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Experimental Science Series

I.

INDUCTIVE ELEMENTARY PHYSICAL SCIENCE

WITH

INEXPENSIVE APPARATUS, AND WITHOUT LABORATORY EQUIPMENT

BY

F. H. BAILEY, A.M.

AUTHOR OF "PRIMARY PHENOMENAL ASTRONOMY," INVENTOR OF THE "ASTRAL LANTERN, OR PANORAMA OF THE HEAVENS," THE "COSMOSPHERE" "100 IN 1 PHYSICAL SCIENCE APPARATUS," ETC.

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PREFACE.

THE course in Elementary Physical Science, of which these sheets form the first instalment, is the outgrowth of various experiments made first in the public schools of Michigan, later in Dr. Felix Adler's Workingmen's School in New York City, and finally, during the past four years, in the private school of Mrs. Quincy A. Shaw in Boston — a school founded by Mrs. Shaw, the daughter of the great naturalist, Prof. Louis Agassiz, for the purpose of developing methods of nature study that will secure to the young student the best preparation for holding through life intimate converse with nature.

The endless source of happiness which this gives is a heritage that Mrs. Shaw has believed will come always to all students who are introduced to the study of the earth by the natural method. The author's educational views were so fully in accord with her own, that she gave him perfect liberty in laying out the work in the Physical Science branches of nature study for pupils from twelve to eighteen years of age. The results reached have been such that many of the best educators of Boston and vicinity have recommended and urged that the course be given a wider field of usefulness.

While this work has been largely the result of class-room experiment, indebtedness is freely acknowledged to various sources, especially to the excellent little manual on "Home-made Apparatus," by Prof. John F. Woodhull, of the New York Teachers' College.

For any testimony that may be wished in regard to the merit of the course, the following are referred to: Mrs. Quincy A. Shaw, Boston, Mass.; Charles F. King, Head Master of the Dearborn School, and Superintendent of the National Summer School; W. A. Mowry, Superintendent of Salem Schools, and of Martha's Vineyard Summer School; S. T. Dutton, Superintendent of Brookline Schools; Larkin Dunton, Head Master of Boston Normal School; A. E. Winship, Editor of The Journal of Education; and Frank A. Hill, Secretary of Massachusetts Board of Education.

F. H. B.

6 MARLBORO STREET, BOSTON, MASS.
January, 1895.

TO THE TEACHER.

No previous knowledge of physics is absolutely necessary, but a clear conception of the *object* aimed at is imperative, in order that the work may be done in a truly scientific manner, and the highest success attained. That object is not primarily to give the pupil a few physical facts out of the great abundance of truth, a few essentials of which is all that is possible in any course, but to cultivate his powers of observation and independent thought. Every young child possesses these powers and is eager to use them, but a system exclusively of book-education tends to destroy them. Some one has truthfully said — "No injustice would be done to a teacher if his skill and the educative value of his lessons were measured by his success in making children reason out conclusions from observed or stated facts"; and we may add that for the best discipline those facts should be observed, not stated. *That* education is of the most value in every walk of life which not only enables its possessor to reason correctly upon facts possessed, but which gives him the power of keen and accurate observation by means of which to collect the facts for himself, and prevent imposition from others. Seeing is not so simple an act as many suppose. Every scientist knows that it is one thing to turn the eyes towards an object, but quite another thing to see what is there. Every one's observational powers need cultivating, and "Observation Lessons" are of value for this purpose, but doubly valuable when so arranged as to become an incentive to logical reasoning.

In planning this course these two objects have been kept in view, and they should be continually before the teacher in charge. If the course is properly taught, pupils who have been in the habit of learning, or trying to learn, without independent thought, find that it is impossible to do so in this work. They are compelled to use their eyes in collecting facts, to put these facts together, and to draw conclusions from them. These processes at their command, they are then prepared for the great school of life, but without having acquired these processes no amount of accumulated facts are of much value. Teachers who have never tried this method will be astonished by the ease with which children adopt it. At first, if their previous instruction has been entirely by the memory method, this one seems to fail completely. The pupils can use neither hands, eyes, nor minds. They cannot experiment successfully nor see more

than a small part of what happens when the experiment is done, to say nothing of thinking out what it all means. But I have not yet had a pupil whose habit of leaning upon book or teacher was so strong that it did not give way, within a brief space of time, and let some degree of self-activity show itself. In training the pupil to self-reliance, it is at the very beginning that the skilful teacher has the opportunity of doing his best work. I have tried several methods; one extreme is to assist the pupils in every step at the beginning, and wean them gradually; the other, to throw them entirely upon their own resources from the very beginning. Of the two extreme methods the latter is the better, provided the pupil can be prevented from becoming discouraged before he gets a start.

The particular method in which you conduct your class will, of course, depend upon circumstances. Only general directions can be given. Though you have no *teaching* to do, that being done by Nature, the best of all teachers, nevertheless you should *teach* (if we may use the paradox) by the most successful method — that of example. *Be* a student of nature with your class, and *acknowledge* yourself such. Have a set of the apparatus, try the experiments, and write your inferences just as your pupils do, either at the same time or previously. You will become interested in the work, and that interest will spread to every pupil. That, at least, has been my experience. Children are imitative, and when they see you doing and enjoying interesting experiments they will wish to do them also. At the same time you can easily appeal to another element which is still stronger in most children — that of emulation; not an unworthy incentive to appeal to, especially if it is done with skill. They will compare their inferences one with another. Get them to compare with yours. You should also examine their written work, and commend all of it that shows independent effort. Frequently you can commend pupils for their discoveries, at the same time that you criticise their statements of facts. Always commend when you can, and criticise with moderation.

There is no better way to become acquainted with your pupils, and no better opportunity for doing individual work. It is sometimes claimed that it is impossible to individualize with the pupils in our public schools when the classes are large; but by this method it becomes comparatively easy. After school you have in your possession the notes written during experiment hour, and through them you rapidly become acquainted with your pupils, and see just how you can best help them. Frequently they need no help, with the exception of some brief marks agreed upon to indicate the mistakes you wish them to correct. Some pupils may need a word of encouragement or direction, and this is usually more valuable if given in writing, though sometimes it is better to speak to them privately. I seldom speak to a pupil in class, unless it is in a whisper, for the class hour should be a silent one on the part of teacher as well as pupils. If you would have it quiet, keep quiet yourself.

For suggestion for correcting books or papers, see note to "Author's Letter to Pupils" (Lesson Sheet No. 1). This method of studying science furnishes one

of the best opportunities for discipline in English composition; for pupils have something to write about, consequently essay-writing becomes easy and pleasurable, and pupils form the invaluable habits of writing upon subjects about which they know something, and of expressing their own thoughts and discoveries. In fact, the many incidental benefits derived from the course are of more value than even the physical knowledge gained. Moreover, aside from the particular physical facts that the pupil discovers, there are general ones of much greater value which can neither be understood nor appreciated unless reached through the individual experimental method; such as the fact that the answers obtained from nature depend upon the questioner; that they approach the truth in proportion as the question is properly put, and the answer carefully read; the immutability of the operation of nature — the fact that exactly the same causes always produce exactly the same results; the fact that there is no such thing as chance, every effect having its cause; the fact that the so-called "natural laws" are simply our explanation of Nature's uniform operations. By this method of study, as one of our critics has put it, "the pupil comes to see things as they are, and not as he thinks they ought to be."

APPARATUS.

Of no less importance than the outline of the course in physics is the apparatus with which the experiments are performed. To meet the wants of grammar schools, the apparatus should be neither extensive nor expensive, but it should be sufficient and of an interesting character. In order to obtain from it the best discipline, not only should the apparatus itself be carefully considered, but the means by which it is provided. Theoretically, the plan for using home-made apparatus is the best, but this plan has usually failed to be very satisfactory in practice, because of the crudeness of the method by which it was attempted. Pupils will do much in the line of making their own apparatus after they have become interested in the work, but generally not at first.

We have found it the best plan to provide the pupil at the beginning with simple apparatus for trying interesting experiments; then to lead him, after his interest in experimental science is aroused, to increase his stock by such pieces as he can easily make for himself. No matter how simple it is, he takes more interest in experimenting with apparatus provided for the purpose, especially if it is of his own make, than in using articles not set apart or especially fitted up for his purpose. Just as the little girl loves her corner play-house, with its miniature tea-set or shelves of broken crockery, so the older child loves a little work-shop or laboratory, with its supplies of his own making.

Interest the pupil in experimental science; then provide him with files and a little glass and rubber tubing, and he will find his own cans and bottles, and make his own

apparatus. We have seen this method produce such excellent results that we cannot too earnestly recommend it.

In order, however, to adapt this work to the widest possible range of conditions, it is published in two courses, one within the other. The briefer one, given on the second page of each sheet, is complete in that it brings out every essential principle of the subjects treated. The course, together with the apparatus which we provide, is adapted to such schools as, for any reason, cannot adopt the home-made apparatus plan.

On the fourth page of each sheet, running parallel with the briefer course, is given auxiliary work; this consists of clearly illustrated directions for making extra apparatus for experiments which will be found useful, either to bring out the principle sought in a different and more striking manner, or to furnish interesting applications of laws already learned.

To make applications is as essential in the study of physics as in arithmetic, and for that purpose a variety of experiments is better, and far more interesting to the child, than a number of problems. In a very few cases (two or three only, in this first course), where applications by experiment are not practical, problems are given.

Another benefit afforded by the "Auxiliary Work" is that it furnishes an easy entering wedge for manual training-work, the great intellectual and moral, as well as material value of which is now conceded by our best educators. Whenever it is possible, pupils should be permitted, or even required to make their own apparatus. Except the drilling of holes in glass bottles, it can be readily done — even this is not so difficult as at first it seems; it has been repeatedly done by the younger pupils of the author's classes. Not only does the pupil take more interest in performing the experiments, with apparatus of his own making, but he is at the same time training the hands as well as the mind. Moreover, there is a fascination in the endeavor to acquire precision in either wood or in metal working — there is an especial fascination in the manipulation of glass designed for apparatus. Pupils have willingly devoted most of their leisure time to such work — with the broken ends of three-cornered files, drilling holes in thick glass bottles — making them true with rat-tail files — bending and blowing glass tubing — in fact, themselves making from beginning to end, apparatus capable of use for fairly precise quantitative results. They did not always exactly reproduce things they had seen, but exercised their inventive powers, and occasionally produced something new. Thus these young pupils became not only *discoverers* in the field of physics, but *genuine inventors*, and they obtained a better education by such efforts than book study alone could ever have given them.

DIRECTIONS FOR OBTAINING MATERIAL AND MAKING APPARATUS.

Illustrated instructions in glass-working that will be useful to all, whether provided with the regular apparatus or not, are given on early lesson sheets, under the heading

of "Auxiliary Work"; but a few preliminary directions will be especially helpful to those who make *all* their own apparatus. The body of the "100 in 1" apparatus (which, together with the lever, is all that is absolutely necessary for this first course) may be made of almost any wide-mouthed bottle. The most difficult part of the work lies in making the holes. I know of but one way that is generally practicable for the student, and that is the one mentioned above as used by my own pupils. Holes may be made with a hard steel drill held in a carpenter's brace, but the drill requires frequent sharpening, and the novice will break more bottles than when using a broken file held in the hand. In some localities machinists can be found who will drill them. It is claimed that glass is more easily drilled when wet with turpentine, but I find that water does just as well either with file or drill, and I have frequently made the holes with files without using any liquid. If a file is used (and an old worn-out one is just as good as any), when the corners become dull lay the end on a piece of iron and break off the end with a hammer. After a little practice a very small bit at a time can be broken off, and so the file can be used for drilling many holes. Hold the bottle firmly, and be satisfied with slow progress, especially when the hole is nearly through.

It is advisable to obtain the rubber tubing first, then to make the holes just the size for it to fit snugly. The tubing, obtained from druggists, school-supply, or rubber dealers, should be of the best quality. Nothing is more unsatisfactory than poor rubber for the short pieces that unite glass tubes and bottle. For that purpose even the best quality, if very thin-walled, does not work well. Each set of apparatus requires about three feet, and, if the best is obtained, the short pieces can be cut from the long one, and, if lost, easily replaced. One inch, however, of the best quality and thickness, together with three feet of cheaper tubing (if it is not the poor, half-clay stuff, which you can detect by rubbing with the fingers), will answer very well. The soft glass tubing should be of medium thickness, for, if thin, it breaks too easily for children's use. A good quality is furnished by school-supply dealers, at prices from fifty to seventy-five cents per pound. The glass tubing should be a very little larger than the hole in the rubber, so that it will make the connection with the bottle not only water- but air-tight, even under the pressure of two or three atmospheres. As the glass tubing is sure to vary somewhat in size, select carefully that which fits best for pieces that are used in bottle holes. Other sizes may be used for Pressure Gage, Equal Armed Siphon, Siphon Fountain, etc.; even the pieces to be used in the stopper may vary more than those in bottle holes. The latter should not vary a thirty-second of an inch in order to work well. The variation may be greater, however, with thick than with thin rubber connectors or packing.

Corks, if of the best quality, may be used quite successfully for most of the experiments, though rubber stoppers are *much* better. If corks are used, soften by rolling them on the floor with the foot, using considerable pressure, after which make the holes with a rat-tail file, if not provided with regular cork-borers. If rubber stoppers are

used, get the best; though the difference in price of rubber stoppers is considerable, it is not comparable with the difference in satisfaction afforded, and the best will last much longer without becoming hard. We have been using some for four years that are yet excellent; and others that were very good at first are now so hard as to be utterly worthless. The difference in the length of wear of rubber tubing is even greater than that of stoppers. We have four-holed stoppers of the best shape and material made on purpose for the work; but the best quality with two holes, always to be found on the market, do just as well for nearly every experiment, provided they fit the bottles perfectly. They should enter but a very short distance, and should not flare enough to prevent being crowded in, nearly their entire length. Most stoppers flare too much to work well in some experiments, unless the neck of the bottle flares nearly as much. The holes should admit the glass tubes easily, when the stopper is not inserted in the bottle. For these reasons, stoppers and rubber tubing should first be selected, then glass tubing obtained, and the holes in the bottle made to correspond. Stoppers of the same make and number are of the same size, but not so are the mouths of bottles of the same "batch." They vary more than most dealers will admit. Hence the stopper and the bottle should be seen to fit perfectly before labor is expended in hole-making.

If you collect pickle or similar bottles (which can usually be done cheaper than buying from dealers) and order stoppers and tubing by mail, specify that the outside diameter of the glass tubing must be the same as that of the hole in stopper, and the diameter of hole in rubber tubing a *very* little less.

We give below the price and number of the best two-holed stoppers furnished by the Franklin Educational Company of Boston (as satisfactory a company as we have ever dealt with), for the smallest-mouthed bottles that are convenient both to obtain and to use.

No. 10, price 45 cents, is a trifle too large and No. 9 is not large enough for a $1\frac{1}{4}$-inch hole, but just right for sizes between $1\frac{1}{4}$ and $1\frac{3}{8}$ inches. From $1\frac{3}{8}$ to $1\frac{7}{16}$, No. 11, price 50 cents. From $1\frac{1}{2}$ to $1\frac{5}{8}$, No. 12, price 55 cents. No. 12 is exactly $1\frac{1}{2}$ inches diameter at the smaller end, hence will not work well for all experiments in a $1\frac{1}{2}$-inch mouth, but will for one a trifle more or less than $1\frac{5}{8}$. These stoppers have holes the same size, namely, $\frac{1}{4}$ inch diameter; No. 9 has smaller holes. Price of an *excellent* rubber tubing to fit $\frac{1}{4}$-inch glass is 8 cents per foot; of the very best (the same we use and furnish), 10 cents. The same size tubing (half clay) can be bought for 4 cents.

THE "100 IN 1" PHYSICAL SCIENCE APPARATUS.

In order to meet the wants of such as cannot make all their apparatus, we furnish sets for the first course (the qualitative study of water and air), at the lowest price consistent with the best material and workmanship. These sets include everything needed by each pupil, with the exception of a tin spice, or baking-powder can and

cover, which he can usually bring from home. Instead of bottles with drilled holes we have devised a glass cylinder, the "Apparatus," which is much better. This is shown in the cut, together with the largest number of attachments used for any one experiment. This cylinder is made of clear pressed glass, consequently mouth and holes do not vary in size, the latter, for the easier admittance of connectors, flare slightly. It is $5\frac{1}{4}$ inches tall (more than $2\frac{1}{2}$ times that of the cut), $1\frac{5}{8}$ inches in diameter, with a thickness of $\frac{1}{8}$ inch at the top, which increases regularly to $\frac{1}{4}$ inch at the bottom. The thickness of the bottom (the only thing which can vary, and slight variation there does not affect its utility) is from $\frac{1}{4}$ to $\frac{3}{8}$ of an inch. It is not easily broken, even by a fall of considerable distance.

EXP. 24.

ADDITIONAL APPLIANCES FOR EACH PUPIL OR SCHOOL.

A few articles easily obtained, differing somewhat according to circumstances, are needed, together with the regular "100 in 1" apparatus. A *dish* of water for each pupil, from which to supply the bottle, and in which many of the experiments are performed, is the only one absolutely necessary under all conditions. We mention several used for that purpose, that choice may be made according to circumstances. A somewhat expensive thing, but the best, is the glass battery jar, 6 inches in diameter and 7 inches deep, illustrated in Exp. 8 and 9. A cheap substitute which does very well, in fact just as well in most experiments, is a certain make of fruit jar, $5\frac{1}{2}$ inches deep and 4 inches in diameter, with a mouth of $3\frac{3}{8}$ inches in diameter, illustrated in Exp. 21. Two-quart fruit jars, or large acid bottles, are easily cut off near the top and make excellent water jars. (See easy method of cutting bottles, Auxiliary Work, sheet IV.) A tin dinner-pail will answer, though a glass dish is preferable as the experiments are better seen.

A *wide-mouthed bottle*, holding a pint or more, and a small *towel* are very convenient, since with the bottle, on many days the large dish of water is not needed.

If work is done on sloping desks with lids, *blocks* to level the lids are better than books; if desk tops are stationary and slope, *blocks* are necessary to level a tray on which to experiment.

A *tray* or *shallow pan*. As some water is unavoidably spilled, even the most careful pupil will usually need a pan, unless working on specially prepared laboratory table or where a little water is not objectionable.

Every class should have a rat-tail file for common use, unless each pupil provides his own tools; with this, an awl, or nail, each one can make for himself several valuable additional pieces of apparatus, at no expense in money and but little in time. Corks for extra bottles are easily perforated with the file, so that tubes of the regular sets will fit. Small tin cans, such as those for baking-powder, spices, etc., are easily obtainable, and can be punched with the awl or nail; then the hole can be easily enlarged with the file until the tubes fit. With the rat-tail file holes are easily made through the "edge" of a bottle, then, with *care*, they may be rounded so that the rubber tubes will fit them. Where gas is available, two other files should be supplied, one a "three-cornered," the other a "half-round" file. A gas-jet bottle-cutter is furnished in each set, but a file is needed to scratch the glass where the fine gas-jet is to cut it, and the half-round file to smooth the edges so that they will not cut the fingers. Keep the file wet when in use.

THE LABORATORY.

It is now conceded that the laboratory is one of the first essentials of every well-equipped school, outranking in importance even the library. The education there obtained is more practical and of the kind to which civilization is chiefly indebted. That the laboratory has not found its way into every school is due, in part at least, to the usually great expense of its equipment and maintenance. It is believed that in this course, for one so valuable, the laboratory expense has been reduced to the minimum, and that in no school are the difficulties in the way of its introduction insurmountable. Not only the apparatus itself, but the other provisions for the work, may be more or less extensive, according to conditions. Pupils *can* do all their experimenting at home on the kitchen table, or wherever convenient. It *can* be done on ordinary school-desks, in trays, or shallow pans, leveled with blocks if the desks slope; the apparatus when not in use being kept in the boxes stacked in the corner of the room, or on shelves. In most school-rooms there are one or more walls against which narrow tables can be fastened with hinges and, if in the way, let down when not in use; the cupboards or shelves for apparatus being placed above. If there is not table room for an entire class, the class may work in sections at different hours, in which case sets of apparatus for one section is all that will be needed. It is advisable, however, when convenient, that a room, even though small, be set apart for laboratory work. Its fittings need not be elaborate, tables being the only absolute necessity, though water and gas are exceedingly convenient. Water must be provided in some way, even if it is brought in pails. Gas also is a necessity if glass apparatus is to be manufactured. A jet for each one or two pupils of a section is very convenient, though much may be done with but one jet in the room, by using rubber tubing long enough to bring the gas to the table, where it may be connected with either

a common or a Bunsen burner, or the glass-cutter, according to the work for which it is desired.

Appliances for the second course, which continues the study of air and water, but in a more decidedly quantitative manner, differ but little from those used for the first, some additional apparatus being required and furnished, though most of it is easily made by the pupil. But for the third subject — Heat — gas is necessary for experimenting, as well as for constructing apparatus.

The study of heat *should* follow, and constitute a part of that of air and water, and so fit the pupil for the study, either in or out of school, of the constantly varying phenomena of the seasons, and such practical subjects as house heating, ventilating, etc.

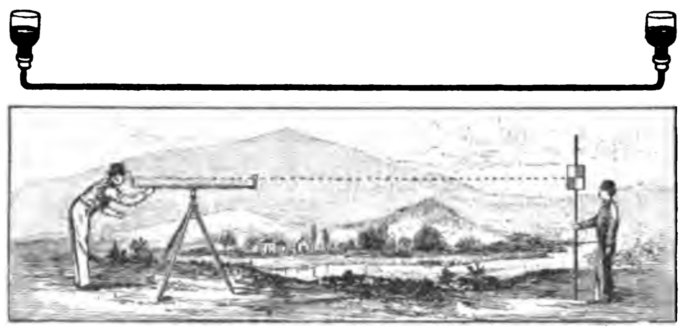
Where a room with tables and gas is not available for grammar schools, but is for the high school, the first, or first and second courses, may profitably be given in the last year of the former, and heat in the first year of the latter.

The teacher will perceive, by examination of the material selected and method employed, what the author has learned by experience, that this course is just as available for high- as for grammar-school pupils. It is for the beginner in physics, whatever his age or advancement in other studies; the older or abler pupils can do more complete work, and perhaps accomplish in one or two months what would profitably occupy others for a year. This great elasticity to adaptability is one of the strongest features of the course.

AUXILIARY WORK.

V.

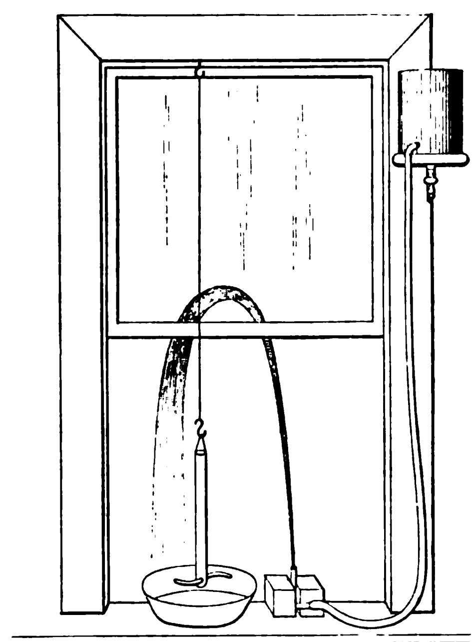
Aux. 3 shows a water-level made of two small bottles with their bottoms cut off, two corks, and a piece of glass tubing; it shows also how the level is mounted upon



Aux. 3.

a tripod stand, and is used for getting the difference in level — or height above the sea — between two places.

Aux. 4. A fine auxiliary to Exp. 17 may be performed by placing a large tin can or pail on a high shelf near an open window, out of which the fountain can play. (To make a hole, see Aux. 1, sheet III.) If not well supplied with rubber tubing, connect two from pupils' sets by means of a short glass tube and insert the elbow jet-tube, held in position by two blocks; or make one that will stand alone, by bending a long piece of tubing twice, each elbow being at right angles to the other. (See stand for gas-jet in glass-bending picture on page 4.)



Aux. 4 and 5.

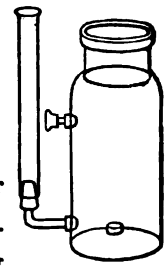
If you have gas, a great many pieces of very valuable apparatus may be easily made of soft glass tubing obtained at drug stores, or purchased by the pound, of school-supply dealers. Do not get the cheap, thin tubing; it breaks easily and is very difficult to work. The only tools absolutely needed are a three-cornered file, a common gas flame and a Bunsen burner.

V.

That which belongs to you is called your property. Call anything that belongs to water its property, and tell briefly what properties of water you have thus far discovered; also state the two leading facts about water pressure. By use of these facts explain the following experiments.

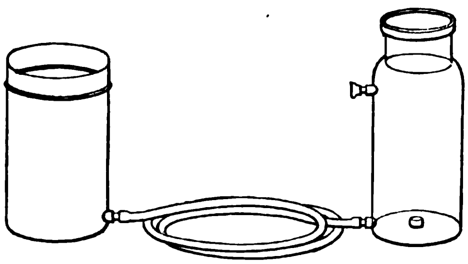
Exp. 15. Fill the Apparatus with water and observe the tube.

INFERENCE. Explain why liquids "seek their own level."



EXP. 15.

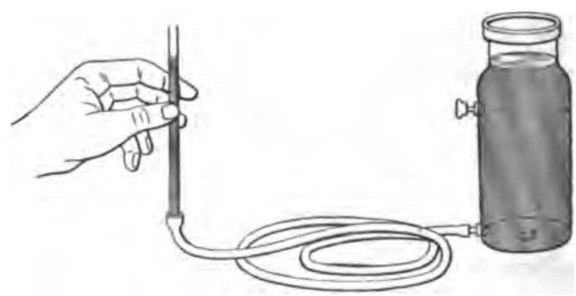
Exp. 16. Connect two Apparatuses with long rubber tube; pour water into one and watch both. Raise and lower one, watching effects. Place them close together near the edge of the table or desk, with the rubber tube hanging over, and fill one with water. Vary their relative positions and the position of the tube as much as possible. Note and explain fully whatever takes place.



EXP. 16.

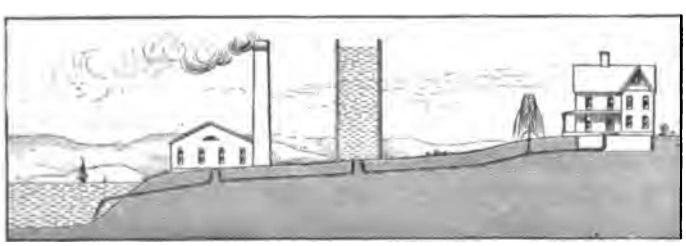
NOTE. — Two pupils should perform this experiment together, or better, each should provide himself with a small tin can (½ lb. baking powder) with hole near the bottom. (To make a hole in tin, see Aux. 1, sheet III.) Did you ever see a carpenter's spirit-level? If so, compare it with the water-level (Aux. 3, page 1) and with Exp. 16; if not, find one and study it as soon as convenient.

Exp. 17. With the Apparatus full of water, raise the jet-tube till it contains no water, then lower it till a fountain is formed.



EXP. 17.

INFERENCE. 1. Explain how water from reservoirs is supplied to towns and cities. 2. Why are reservoirs built on hills? 3. Why do cities located in level countries build standpipes or water towers? 4. On which floor of tall buildings thus supplied with water does it escape most rapidly, and why? 5. Write about this subject as fully as you can, and see if you can apply the same principle to explain country water supply by wells or springs. See Aux. 4, page 1.



DIRECTIONS FOR ADJUSTING THE "100 IN 1" PHYSICAL SCIENCE APPARATUS.

Before attempting to perform any experiment, *read these directions carefully and follow them closely.*

In every experiment, unless otherwise directed, the holes in the bottle (see illustration, Exp. 2) or "100 in 1 Apparatus" should be plugged.

To plug the hole in the bottom, stand the bottle or Apparatus bottom upwards, wet thoroughly a $\frac{1}{4}$-inch piece of rubber tubing or "packing"; insert a shot large enough to slightly stretch the tubing just barely into one end; thrust the free end into the hole until the shot-loaded end is even with the outer surface; then, with the thumb push the shot well into the packing. The holes may also be plugged with small corks, or with rubber stoppers. The shot-loaded piece of rubber tubing, however, makes by far the best plug. The side holes may be plugged in the same manner. To remove a plug, push the shot through with a nail; then remove the packing.

The side holes may be plugged with the small glass jet-tubes (see Exp. 2) as follows: wet a "cap" or $\frac{1}{2}$-inch piece of rubber tubing with a shot in the end, and push it over the small end of the jet-tube; put a piece of packing just barely over the other end; then seizing that part of the packing stretched by the glass, push it into the hole, and then with a twisting motion thrust the tube in until it is held firmly.

To connect *any* glass tube with the bottle or apparatus, put a piece of packing over the end of the tube; grasp it at the place where the rubber is distended by the glass; insert the packing into the hole, and then push in the tube until it is held firmly. If the rubber packing is pushed clear through the hole — which may happen if the glass tube is the least particle smaller than it should be — thrust the end of the glass tube a little further into the packing, wipe the latter dry, and try again.

To remove a jet-tube or other glass tube from a hole, seize it firmly near the packing and draw it out with a twisting movement.

Never leave wet packing, caps, or other rubber on a glass tube; after drying they are apt to stick to each other so firmly that the glass may be broken in removing it. The glass tubes are not easily broken, but they are not intended for rough usage; with decent care they will last a lifetime.

If a long piece of rubber tubing has been used with water, blow the latter out before putting the tubing away. Sheet rubber should be dried with a cloth.

Do not attempt to perform any experiment in a careless, slipshod manner. If you are not careful and orderly, you cannot hope for success in any pursuit. Begin now by being careful of your apparatus. Try to be exact; always do your work neatly; and always put your apparatus away in good order when you have finished your work.

II.

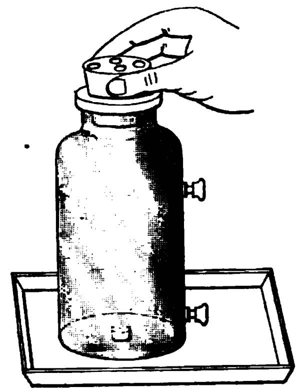
Experiment 1. Fill the Apparatus, or bottle used instead, to the brim with water, and insert a finger.

OBSERVATION. What happens?

INFERENCE. Why?

Exp. 2. Fill the Apparatus with water; crowd a large shot or glass plug into each hole of rubber stopper, then try to insert it tightly.

OBSERVATION AND INFERENCE.



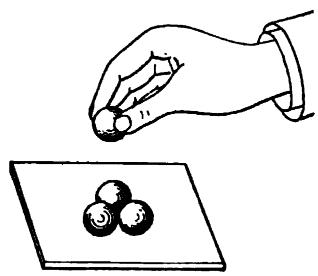
EXPS. 2 AND 3.

Exp. 3. Remove the plug from one hole of the stopper, then insert it tightly.

OBSERVATION.

INFERENCE. Why can you easily insert it now? What do these three experiments teach you about water?

Exp. 4. Weigh or "heft" the Apparatus; fill with water, and weigh or heft again.



EXP. 6.

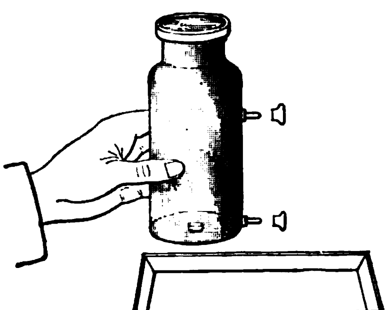
INFERENCES. 1. What does this experiment teach about water? 2. Would it have weight if there were no force pulling or pushing it towards the earth? 3. Is it the same force that causes a ball thrown upward to fall back to the earth? 4. Do you know its name? [It has a name, but we do not know much about it.] 5. Towards what point in the earth does this force pull everything on the earth? 6. Draw a circle to represent the earth, and illustrate the direction objects fall on different sides of the earth, showing where they would meet if they could fall through the earth as easily as through air.

Exp. 5. Cap the small ends of the jet-tubes, and insert them in the side holes, as in Exps. 2 and 3, fill the Apparatus with water, and remove the cap from lower jet-tube.

INFERENCE. In what other direction than downwards does water press?

Exp. 6. Upon three marbles, touching each other on a smooth surface, place a fourth.

INFERENCE. What causes the three to roll apart? Now explain why water presses *sideways*.



EXP. 7.

Exp. 7. Fill the Apparatus with water, hold it above the pan and open both jet-tubes.

INFERENCE. What more does this experiment teach you about *side pressure* than did Exp. 5.

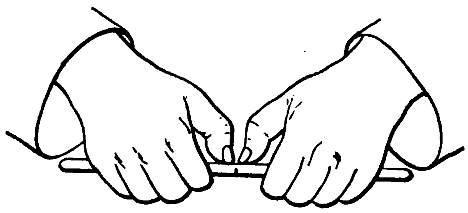
NOTES.

NOTES.

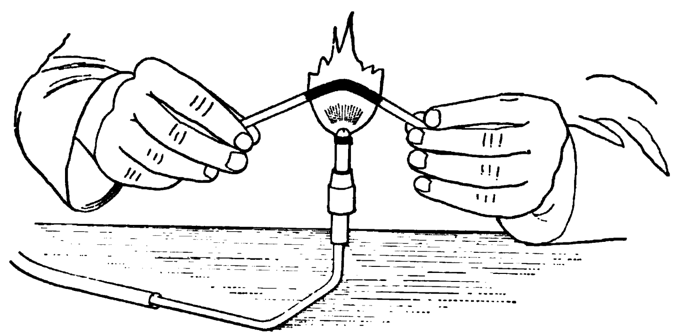
NOTES.

V. — *Continued.*

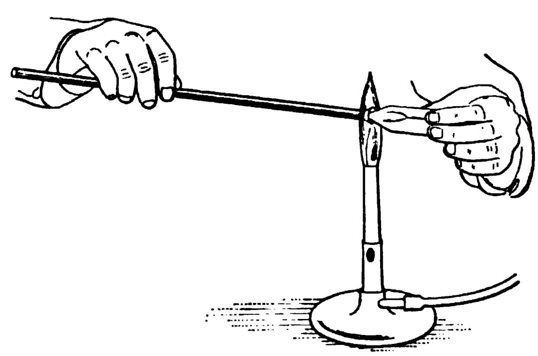
To break the tubing squarely, scratch it with the file, then hold it with the



thumbs opposite the scratch, and break as you would a twig. The sharp edges are easily removed by means of a file; they may also be melted smooth in the Bunsen burner. To close the end, or to partly close it so that it may be used as a jet, hold it in the hottest part of the Bunsen blaze, and keep turning it till the hole is small enough. To bend it, use a common gas jet, not very large, and turn it while heating. A little practice will



enable you to do it neatly. The cut below shows how to make a small funnel from a glass tube, by using the Bunsen burner and a piece of charcoal sharpened like a pencil.



If not supplied with gas, you can shape *thin* glass tubing with an alcohol or a common flat-wick oil lamp, but it is very difficult work. Skillful glass-blowers can work with crude apparatus and poor materials, but pupils not accustomed to the manipulation of glass require the best of appliances. Do not try to hurry your work. When the glass begins to yield under the action of the heat, do not bend or shape it too rapidly. Unless necessary, do not bend a tube at too sharp an angle. In the above cut the tube is bent at a sharper angle than is usually desired.

NOTES.

IV.

Exp. 12.* Fill the bend of the pressure gage two-thirds full of water, and slowly insert the lower end several inches into the Apparatus or dish of water.

EXPS. 12 AND 13.*

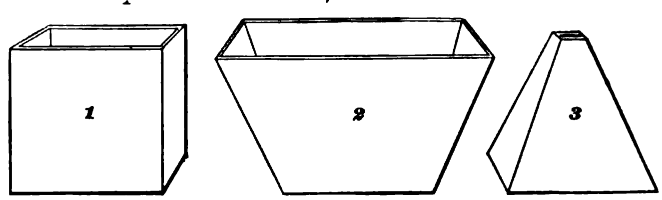
Exp. 13. Attach the small U piece to the lower end of the pressure gage, and repeat above experiment.

1. Do inferences in Exp. 12 and Exp. 13 agree with conclusions in "Lesson in Reasoning"? 2. Can you now tell more definitely *how* rapidly pressure increases?

Exp. 14. (See Aux. 2 on page 4.) Insert pressure gage to the same depth in water contained in dishes of various *sizes* and *shapes*.

EXP. 14.

INFERENCES. 1. Upon what *one thing only* does the upward water pressure against the air in the gage depend? 2. Would it be any greater at the same depth in a lake or pond? 3. Upon what *two things* does the downward pressure upon the bottom of a dish full of water depend? 4. Is the pressure on the bottom of dish *2*, below, greater than that on dish *1*? 5. How do you know. 6. Is the pressure on the bottom of either dish just equal to the weight of the water it contains? 7. In the other, is it greater or less than the weight of the water? 8. With dish *3*, how does the pressure on the bottom compare with that of the others? 9. Why? 10. How does the pressure compare with the weight of the water? If the inside of dish *1* is just 1 foot square on each side, it will hold 62.5 lbs. of water. 11. What is the pressure against one side of the dish, if full of water? 12. What is the total pressure against the sides and bottom? 13. What is the total water pressure against sides and bottom of a dish twice as long, but the same width, and holding the same amount of water? Make a drawing of the dish, or a diagram of the bottom, one side, and one end. 14. A dish is twice as long and twice as wide as No. *1*, but holds the same amount of water. What is the total water pressure on bottom and sides? Draw or diagram the dish. 15. What is the depth of each dish? 16. As a general fact, is the *total* pressure of a certain amount of water more if held in a deep dish with small bottom, or in a shallow dish with large bottom? 17. A deep dish and a shallow dish, both with perpendicular sides, hold each the same amount of water; how does the pressure on their bottoms compare?



QUESTIONS 4 TO 14.

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* If the right arm of the pressure gage in the "100 in 1" set of apparatus is considerably shorter than is shown in the cut, it must be lengthened by one of the pieces of straight tubing and a rubber connector.

NOTES.

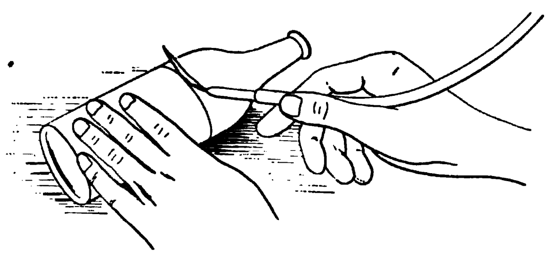
AUXILIARY WORK.

IV.

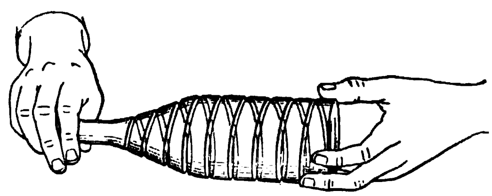
Aux. 2. Though most pupils see the principle in Exp. 14 without extra dishes, better have two additional pieces, a beer bottle and a lamp chimney or tin funnel, the latter corked and standing in a bottle. Being needed but once, and for only half a minute, one set will do for a class if placed where the pupils can use it in turn — each using his own pressure gage if the work is all done at school; all with the same gage, if regular experiments are done at home, and only the auxiliaries at school. A very neat funnel-dish is made by cutting a beer bottle, corking and standing the neck part inverted in the lower.

EASY METHOD OF CUTTING GLASS BOTTLES.

In addition to the things found in pupils' sets, coal gas and a sharp three-cornered file are required.



Scratch the bottle with the file along the edge of a strip of paper, tied around it for a guide. Remove the paper, and rolling the bottle, heat it along the scratch to a little distance ahead before the crack starts, or the latter may leave the mark. With thin glass, the crack will follow the gas jet quite steadily without much heating ahead; but thick glass cracks by "fits and starts." After some practice you can dispense with the scratch, except an inch or two where the crack is to be started. Sharp edges are smoothed with a wet file. A "half-round" file, one that is flat on one side and curved on the other, is best for this purpose, especially for the inner edge. Thin bottles may be cut with a flat-wick oil lamp, but the line must be scratched entirely around, and even then the glass will not always crack where desired.



With little practice bottles may be cut into spirals from end to end, after which they can be stretched considerably without breaking; when released the glass will resume its original length with a sharp click, showing its great elasticity. Test-tubes, lamp chimneys, thin glass tumblers, and beakers are very easily spiraled.

The latter the author has so cut as to be stretched to twice their original length. The smaller part of a chimney, like the one used for Aux. 1, on sheet III., the author cut into a spiral of 60 coils within a length of 8 inches. The diameter of the chimney was $1\frac{1}{4}$ inches. If you can estimate the present length of that 8-inch piece of glass, you will find that it is more than three times that of your height.

NOTES.

XVIII.

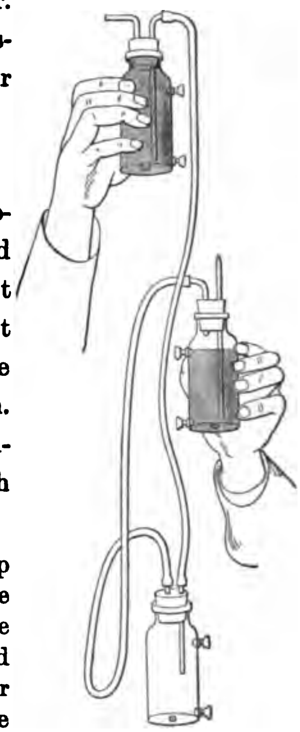
Exp. 75. As this experiment requires parts of apparatus from two sets, and assistance in starting it, two pupils would better work together. One should hold the funnel and bottle full of water as illustrated, the other pours water into the funnel to start it.

Exp. 75.

INFERENCE.

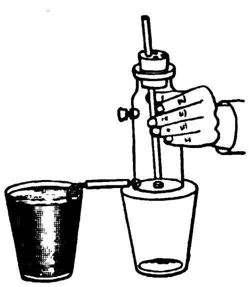
Exp. 76. Arrange three Apparatuses as illustrated, and blow through the open bent tube to start it. Vary the height of the fountain piece and notice the effect upon the fountain. Try the same with the "fountain head," the bottle in which you blew.

INFERENCE. Explain each step of the experiment, and be sure to tell what variations affect the height to which water rises, and what the length of stream after the water leaves the jet-tube. See Auxs. 25–30, sheets 12–15.



Exp. 76.

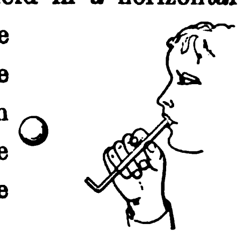
Exp. 77. A little care is necessary in order to get the tube exactly over the bottom hole, and near enough to it to work well. To give the necessary inclination to the tube, crowd the rubber stopper in more on one side than the other; it is easier to use a common cork with a hole in the center. Blow hard through the tube, and water as well as air is blown out.



Exp. 77.

INFERENCES. 1. What must be the condition of the air in the Apparatus before water can rise into it? 2. Explain as fully as you can how the necessary conditions are produced. See Auxs. 31 and 32.

Exp. 78. Blow hard through the tube held in a horizontal position, with wooden ball held an inch or more above the opening near the bend; let go the ball, and keep it floating in mid-air. After acquiring some skill with the tube in that position, incline it as shown in the picture, and see how much you can do so, still keeping the ball in the air. See Auxs. 33 and 34.



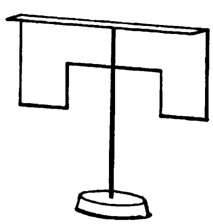
Exp. 78.

NOTES.

AUXILIARY WORK.

XVIII.

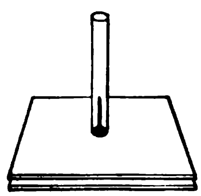
Aux. 31. Cut and bend a piece of heavy writing-paper or light cardboard as illustrated, and balance it on the point of a long needle. A large flat cork or any corked bottle makes a good stand for the needle. Fan one end with a piece of cardboard, or with the hand, moving it from the center outward, and the paper will swing towards the fan.



Aux. 31.

Inference.

Aux. 32. Insert a glass tube tightly into a hole in a piece of thick cardboard. Insert a pin to its head in the center of a piece of thin cardboard of about the same size. Place the former over the latter as illustrated; while blowing through the tube, lift it from the table, and the lower card will follow. In fact, you cannot blow it off.

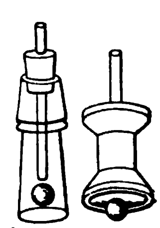


Aux. 32.

Inference.

Aux. 33. Much better than the wooden ball, in Exp. 78, is one of pith or of cork, but still better are the "oak-galls" or "oak-apples" which grow upon oak leaves, as the result of the sting of a certain species of gall-fly. The oak-gall after becoming ripe has a hard shell, but is very light, and by a little skill can be kept in the air a considerable distance from the tube for nearly a minute. The best size is at least an inch in diameter. Of course a straight tube can be used by throwing the head back, and with skill the tube can be brought down till it is more nearly horizontal than perpendicular, and the oak-gall still kept revolving in mid-air. A quill toothpick, cut square at the outer end, makes a very serviceable tube for this and several other air experiments.

Aux. 34. Cut or break off the neck of a bottle (a smoothed edge is not essential), and fit it with cork and tube as illustrated. Hold it well down over one of the small wooden balls and blow through the tube. The ball rises into the bottle neck, and you cannot blow it out even with a powerful bellows. Use also a marble. A glass marble shows beautifully the rotations it makes. The same piece of apparatus may be made with a common spool by cutting out a cone-shaped cavity in one end, but a white glass bottle-neck makes a much prettier piece.



Aux. 34.

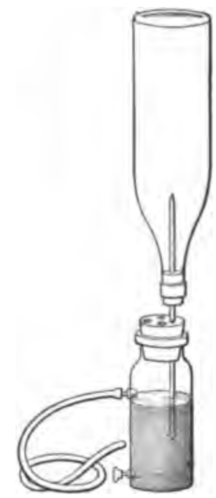
Inference. What lifts the ball against the strong current of air which one not accustomed to the experiment would expect to see blown away?

NOTES.

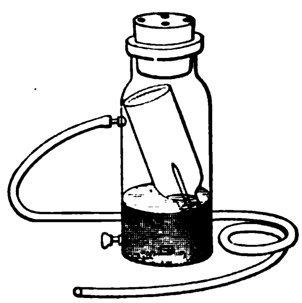
XVI.

Exp. 64. Connect a tall bottle to the Apparatus with the longest jet-tube as illustrated. Suck the air from the Apparatus, observing what is happening to the air in the bottle at the same time. Pinch the tube, rest your throat, and suck again till you remove as much as you can; then let go the rubber tube.

INFERENCE. Explain the operation of the fountain, and the process of preparing conditions necessary for its success.



EXP. 64.



EXP. 65.

EXP. 66.

Exp. 65. Fit a jet-tube tightly to the small bottle, and put it inside the Apparatus. Pour in a little water, cork tightly, and suck out the air.

INFERENCE.

Exp. 66. With a short rubber tube on the large end of the jet-tube suck the air from the Apparatus (or any bottle with a common cork and tube), pinch the rubber while transferring the end in the mouth to a dish of water, then release it.

INFERENCES. 1. How much of the air did you get out? (After a little practice you can exhaust more than half of it.) 2. Do you *draw* it out? 3. What forces it out?

Exp. 67. Try to suck water from the Apparatus completely full.

INFERENCE. Why cannot you do so?

Exp. 68. With but little water in the Apparatus and with the tube reaching into the water, try again.

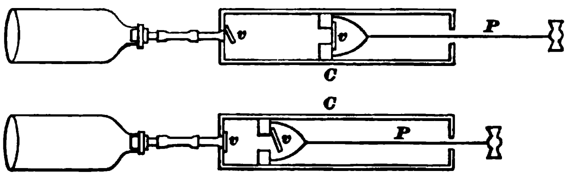
INFERENCES. 1. Why can you get water now? 2. How does air differ from water as regards the cohesive force between its particles? 3. In place of the cohesive force, what kind of a force does air possess? 4. How does it act compared with cohesion? 5. Compare with discussion of Exp. 51. See Aux. 20.

NOTES.

AUXILIARY WORK.

XVI.

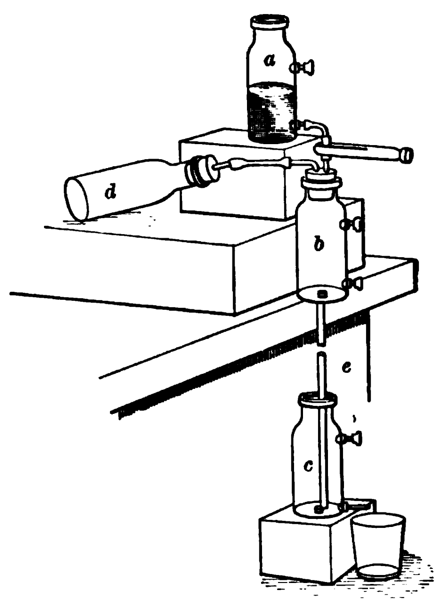
Aux. 20. The diagrams below represent a simple form of the air-pump used to suck or "exhaust" a part of the air from a bottle. *C* is a cylinder in which works the piston *P*. *v*, *v* are valves or little doors opening one way only.



Aux. 20.

Inferences. 1. Explain its action. When the piston is being pushed in, are the valves open or shut? Are they open or closed when the piston is being pulled out? Tell about each one in each case. 2. Does the force applied by the hand open the valves? What forces the air out of the bottle when the lower valve is open, and what opens it?

A mercury air-pump may be constructed with parts of three pupils' sets of apparatus. With this pump *nearly all* the air may be taken from a bottle. The apparatus itself is very cheap, but its use requires considerable mercury (none of which need be wasted, however), time, and attention. It is well worth constructing, if only for the purpose of studying its operation. If provided with a retort-stand and a glass funnel, they may be used instead of Apparatus *a*, and its supporting blocks. A screw-clamp for regulating the flow of mercury, is better than the clothespin. In place of Apparatus *b*, one may use a small inverted bottle with the bottom cut off. A single tube (represented as broken) reaches from *b* to *c*. If the pump is used for practical purposes, and a nearly perfect vacuum is desired, this tube should be about two and a half feet long, with a thicker wall and smaller hole than those commonly used. If used only for the purpose of study, two or three pieces well connected with short pieces of rubber tubing will answer very well. If a small amount of mercury is used, the experimenter is kept busy pouring it back into *a*. Two tumblers should be used; then by tipping *c* a little to empty it, time enough during which there is no flow from it is obtained in which to change dishes. If the glass tubes between *b* and *d* do not nearly or quite touch each other, the rubber tube will be compressed (as shown in picture) so much as to prevent getting a free flow of the air from *d*. If they do touch, by keeping the rubber attached to *d*, with a little care they can be disconnected without allowing any air to enter. In order to secure the largest number of observations, tube *e*, in which they are made, should be a long one.



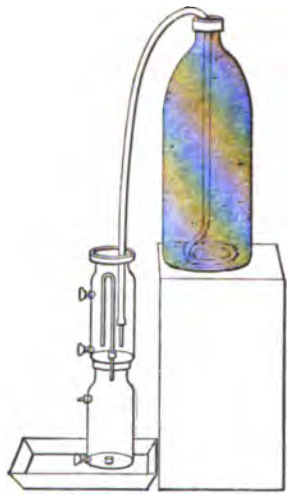
Exp. 77.

NOTES.

XV.

Note. — For the illustration of Exp. 58, see previous sheet.

Exp. 58. Insert the end of the longer arm of U-tube into the bottom hole of the Apparatus till the bend is below the mouth, and fill the Apparatus with water. This is called a Tantalus cup.



Exp. 59.

Inference.

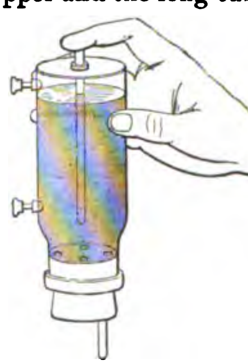
Exp. 59. Arrange a dish with tube to supply a *small* but constant stream of water to the Tantalus cup, and you will have an intermittent flow from the cup. See Aux. 19.

Inference.

Exp. 60.*

Exp. 60.* Fill the double-bend jet-tube with water, hang it over the edge of the Apparatus, and you have a "siphon fountain."

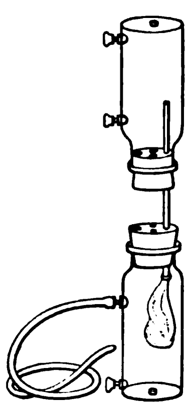
Exp. 61. Place a short tube in one hole of the stopper and the long tube in the bottom hole of the Apparatus. Fill the Apparatus with water and insert stopper. Place your finger over the end of the tube beneath the Apparatus and invert. Use the bottle dropper as you did the tube in Exp. 50 and explain. See if you cannot *invent* a dropper.



Exp. 61.

Exp. 62.

Exp. 62. If the Apparatus and tube are full of water, and you uncap the upper jet-tube, how much water will run out? This is a good test of your previous work on air pressure. Answer first, then verify by experiment.



Exp. 63.

Exp. 63. Borrow an extra apparatus and stopper, or still better, use a large bottle as shown in next experiment. Place in any position and suck out the air.

Inferences. 1. Distinguish between the force that, in this case, fills the rubber bag and "how we breathe" (Exp. 43). 2. How is the air withdrawn from the Apparatus?

* Instead of the tube shown in the cut, use the unequal-armed siphon with a jet-tube connected to the short arm by means of the long piece of rubber tubing. Apply the mouth to the jet-tube and exhaust a little air to start the flow.

NOTES.

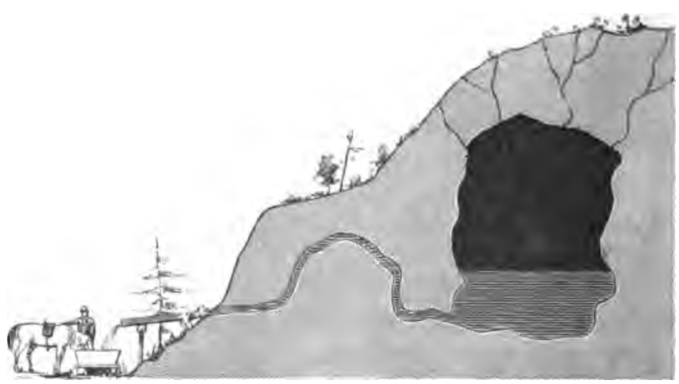
AUXILIARY WORK.

XV.

To study the operation of this pump, use it first with water, without the long delivery, having in its place a short rubber tube hanging in a dish to catch the water. With the hand, alternately compress and release the bulb; note what happens. By experiment find how to hold the pump to deliver a stream of water, and retain considerable air in each bottle; how to retain air in one bottle only; and how to fill both with water. Explain the working of the pump, naming each force in order, beginning with the force that compresses the bulb. Be particularly careful about the second and third forces, for very likely you will overlook one of them. Does the pump act differently with air than with water? Try each, and devise your own means for determining whether there is any difference in principle. The apparatus with delivery tube, shown in the picture, is used to illustrate the circulation of blood. The pump represents the heart; the tube, between the pump and the rattan, an artery; the rattan, the capillaries; the tube beyond, which should rest in the tumbler of water, represents a vein.

Every time you squeeze the bulb, the water spurting from the notch in the glass tube at the right of the rattan illustrates the manner in which one loses blood when an artery is severed. Slip the rubber tube over that hole and work the pump; the slow but steady leaking from the rattan and the other glass notch illustrates how a wound bleeds when capillaries or a vein is cut. With the tube lying on the table while working the pump, press upon the tube, or bend it sharply beyond the rattan; the extra spurt of water from the jet-tube illustrates how the circulation of blood is increased by exercise.

Aux. 19. An intermittent spring is one that does not flow all the time, but has alternate periods of flow and rest. The periods of rest come generally after a long dry spell, and sometimes not till the dry spell has ended and it is again rainy weather. This picture illustrates the conditions of a hill from which there issued such a spring, until a railway was cut through it and the spring was destroyed. In the hill was a cavern seamed with numerous small cracks through which ran the water that filled it. The water flowed out through a single arched opening.



Aux. 19.

Inferences. 1. Explain how the flow became intermittent under varying conditions of weather. 2. Under what conditions might a drought come and go without the flow of water ceasing? 3. If it stopped flowing, how much rain or melted snow would have to find its way into the cave before it started again?

NOTES.

XIV.

Exp. 55. Fill the U-tube with water and, placing a finger over one end, invert and hang it over the edge of the Apparatus or dish full of water, and remove the finger. Raise it until the water runs out in drops, and finally not at all. Experiment till you see how to make it run either slowly or rapidly at pleasure.

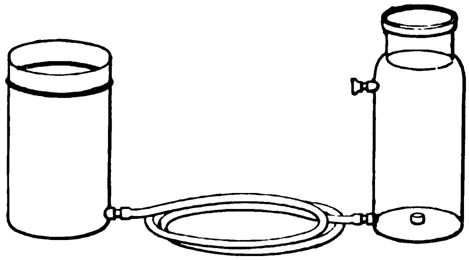
Exp. 55.

Inferences. 1. Infer the difference in conditions. 2. Test your statements by using the unequal-armed U-tube, to see if you gave the conditions correctly. 3. Explain carefully what starts the water running, and what keeps it running. 4. If there were no air in the room, would it run at all? 5. If you think it would, tell how and why. This instrument is called a siphon, and it has a great many forms. Experiment with any other you find in your set. Make one with your long rubber tube, and experiment with it in different positions. 6. How many of the tubes in the "100 in 1" Apparatus set, can you use as siphons?

Exp. 56. Use the same apparatus as in Exp. 55, with the addition of the baking-powder tin and, after the water has reached the same level in each dish, raise first one, then the other, and watch the changing direction of the flow.

Inferences. 1. If you call the perpendicular distance from the highest point of water down to a certain point the length of an arm of the siphon, what is that point in each arm, and is it always at the end of the tube? 2. Which is the longer arm of each siphon?

Exp. 57. With the Apparatus arranged as in Exp. 16, place the latter and a tin dish near each other, fill one with water; as soon as it begins to run into the other, raise the center of the rubber tube as high as possible above the dishes.



Exp. 57.

Exp. 58.

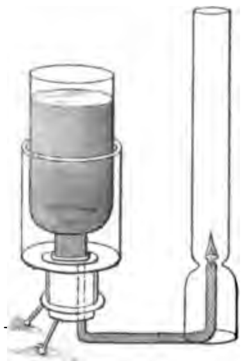
Inferences. 1. What starts the flow, and what keeps it going? 2. Does the force that keeps it running affect it when the tube lies on the table or hangs over the edge? 3. In which of the three cases would it flow just the same if there were no air in the room?

NOTES.

AUXILIARY WORK.

XIV.

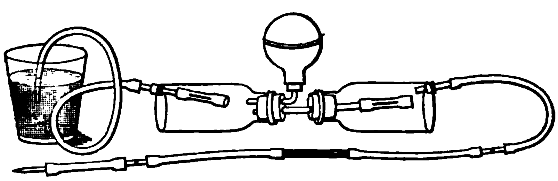
Note. — **Auxs. 29 and 30 are not to be used until they are referred to in the regular work.**



Aux. 29.

Aux. 29. This is a student lamp, the operation of which is easily studied, as with the exception of a cork and two nails, it is made entirely of glass. The cork tightly fits the inverted half bottle, and is perforated for a tube through which the oil reaches the wick. Two nails are driven into the cork and, with the tube, form the support for the lamp. The chimney rests on the tube and two bits of wood, which are separated just enough to allow sufficient draft, the latter being easily adjusted by experiment. This piece, which is easily made, furnishes also a valuable auxiliary experiment in the study of combustion.

Aux. 30. This is an easily made and a very serviceable force-pump for use with either liquids or gases. With a single piece of rubber tubing in place of the long sectional one shown in the picture, it may be used for pumping air wherever in previous lessons the "atomizer bulb" is recommended. It works equally well in pumping or forcing a stream of water. The rubber bulb, which contains no valve, should be as heavy and elastic as possible. One end of a bent tube is fitted tightly into it by means of a piece of rubber tubing, the other end passes through a stopper containing two holes into one of the small bottles. The bottles are connected by a piece of glass tubing which has upon one end a valve like those in the apparatus for pumping water (Exp. 42). A similar valve is placed upon the end of the tube passing through the edge of the other bottle. The holes in the bottles may be drilled each in the center of the bottom; if done with a file they are more easily made in the edges. Glass tubes are fastened in tightly with bits of rubber tubing. The glass tube with the valve on the end should be longer than the bottle. It is first inserted through the neck; then if desired, it may be shortened. The long tube shown in the picture is made of rubber, glass tubes, and a short piece of rattan. The glass tube in the outer end is a jet-tube; each of the other two has a small notch filed in it, and is of such size as to allow the rubber tube to slide over the notch to prevent leakage. The piece of rattan also has a small notch cut in it. A glass tube bent at a sharp angle, inserted in the end of a rubber tube and hung upon the edge of the tumbler, keeps in place better than rubber tubing. (Continued on sheet XV.)



Aux. 30.

NOTES.

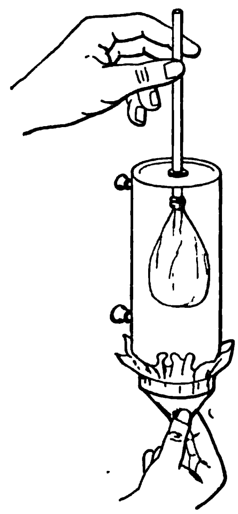
XI.

Exp. 42. This experiment illustrates how we pump water. Insert the long tube with slit rubber valve on the end into the bottom hole from the inside, then pull it through to the rubber. Seize the sheet rubber in the center, pull up and push down alternately, and pump water from the bottle into the tumbler.

INFERENCE. Explain the best you can now, and better later on. See Aux. 14, sheet X.

Exp. 43. This experiment illustrates how we breathe. The Apparatus represents

EXP. 42.



EXP. 43.

EXP. 44.

the chest cavity; the rubber balloon, the lungs. Alternately pull out and push in the center of the sheet rubber tied over the mouth of the Apparatus.

INFERENCES.

Exp. 44 is nearly the same as Exp. 43, only it is performed by using water instead of sheet rubber. Alternately lower the Apparatus into water a short distance and withdraw it. See Auxs. 15 and 16.

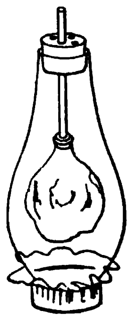
Exp. 45. Tie the sheet rubber over the mouth of the Apparatus and put a jet-tube into each hole, as in Exp. 23. Strike on the rubber and feel the air at the holes.

INFERENCES. 1. Compare with pressure transmitted by water. See Aux. 17. Compare what you have learned about air with what you learned about water. 2. What like properties do they possess? 3. Have you discovered anything which air will do that water will not? 4. If so, tell what it is and where you discovered it. 5. If you have not, after telling in what respects air is like water, tell as well as you can how it differs from water. Then try the following experiments, explaining all you can by means of facts already discovered, but keep your eyes open for new facts about either air or water.

NOTES.

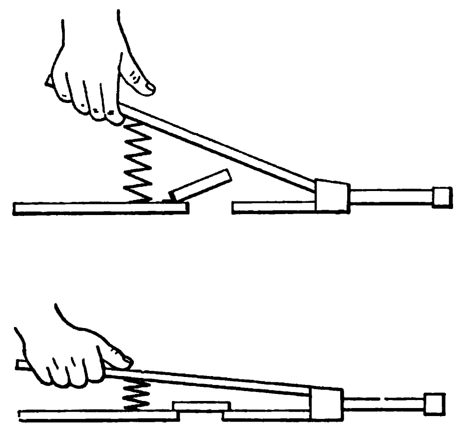
XI.

Aux. 15. A lamp chimney makes a fine piece of "how we breathe" apparatus, and, with a long jet-tube, can be used for a "vacuum fountain."



Aux. 15.

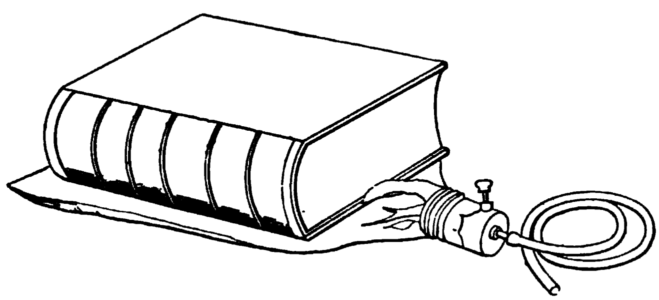
Inferences. 1. Do we "draw in" air through the nose or mouth when we breathe, or simply enlarge our chest cavity and let nature do the rest? 2. Do you think there is any such thing as suction?



Aux. 16.

Aux. 16. Explain the working of a bellows for blowing the fire.

Aux. 17. Fasten the long rubber tube to a hot-water bag (see Aux. 6), place weights of 50 or 100 pounds upon the bag, and blow through the tube. If the bag is large enough, you can sit upon it, and raise yourself with your own breath. For raising a large dictionary, or even a stack of them, a tight paper bag will answer, but it is very difficult to get it fastened air-tight around the tube. To do so, connect them by means of the Apparatus, around open end of which the mouth of bag is tightly fastened.



Aux. 17.

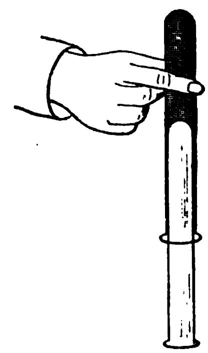
This experiment is sometimes published as a trick, and is called "The Power of the Breath." But the "power of the breath" is only about an ounce. With a properly constructed apparatus, however, a man can, with his breath, lift an ox. *Compare this principle with that of the water-press, Exp.* 28 *and Aux.* 9.

AUXILIARY WORK.

X.

Aux. 13. Half fill the larger test-tube with water, and place the smaller one in it, the bottom touching the water. Taking hold of the larger one, invert them. If they are of correct relative size, the smaller will not fall out, but will rise inside the larger to the top.

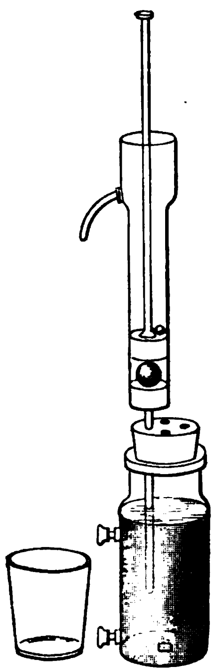
INFERENCE. Why?



AUX. 13.

NOTE. — Aux. 14 need not be tried until after the first Experiment on sheet XI has been performed.

Aux. 14. A fine "suction" or lifting pump is easily made with a straight lamp chimney. A marble and a large shot make the best and most interesting as well as the cheapest valves. The shot will rise an inch or two with the water when the piston is pushed rapidly down, and fall back, perhaps not over the hole; but when the piston starts upward, it gets into place instantly, making a very interesting experiment in itself. The piston should be made of a rubber stopper with two holes, and should work very loosely — in fact it should not pump water without first being primed; then it works so easily that there is no danger of breaking anything. If made of wood, the piston rod is easily pinned into one hole of the stopper; if of glass rod, heat it in the Bunsen lamp till soft, then crowd the ends to produce the bulge which keeps the stopper from slipping up; and by heating the end and pressing it against something hard, a knob is made upon the end which can be forced easily through the hole in rubber stopper. Treat the upper end in the same way and insert the piston from below. It should go in tightly at the end, which is generally a little smaller than the rest of the chimney. The lower stopper may be either rubber or cork, and the tube should not reach quite through it. If cork is used, make the hole from the small end so that its edges may not be torn, in which case the valve is imperfect. If you are not an expert in digging holes in glass, though it is easily done, the spout may be omitted, and the water allowed to run over the top. With the spout, however, the experiment is much more striking. Fill the Apparatus, or a bottle, with water, insert the pump-tube through the stopper, and plug the other holes. Work the piston up and down.



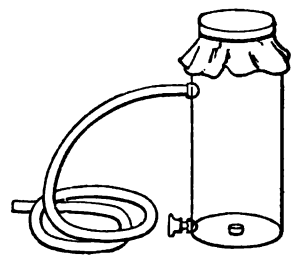
AUX. 14.

INFERENCES. 1. What happens? 2. Why do you not pump water now? 3. Remove one plug from the stopper, work the piston rod, and explain every step of the experiment. 4. Could you pump water from any cistern that was air tight? 5. Is it proper to say that the water is "sucked up," or to call a pump a "suction" pump? 6. What forces it up? 7. What produces the necessary conditions?

NOTES.

X.

Exp. 35. Fill the Apparatus with water and place a piece of card over the mouth. With one hand hold the card in place, while inverting the Apparatus with the other over a dish, to catch the water if the experiment should fail. Remove your hand from the card. In the same way repeat with disc of wood, metal (iron, zinc, or lead), and glass. Repeat, using a piece of wet cheese-cloth, silk veiling, or wire netting. Repeat again, and uncap the jet-tube near the bottom of the Apparatus.

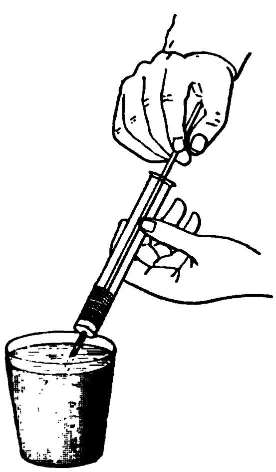


Exp. 36.

INFERENCE. See Aux. 13.

Exp. 36. Tie sheet rubber over the mouth of the Apparatus, and attach the long rubber tube to either side hole. Suck a little air from the Apparatus and pinch the rubber tube to prevent its returning. Turn the mouth of the Apparatus in every direction.

INFERENCES. 1. What more about air pressure does this teach you than did Exps. 34 and 35? 2. Compare with water pressure. 3. What force causes it?



Exp. 41.

Exp. 37. Use your hand instead of the sheet rubber, and suck out all the air you can. Turn your hand over and in every direction. If the experiment is well done, the Apparatus will not fall off. You can hardly pull it off.

INFERENCE. Why?

Exp. 38. Suck the air from the small bottle, and stick it to the upper lip, or else try the next experiment instead.

Exp. 39. Wet a jet-tube rubber cap, squeeze it with your fingers or teeth, and press the tongue against the open end. If well done, you cannot shake it off.

INFERENCE. Why?

Exp. 40. Fill the Apparatus with water, and tightly insert the stopper with all the holes open, after which plug them with the shot. Though the stopper may be easily twisted around in the Apparatus, it is pulled out with great difficulty.

INFERENCE. Why?

Exp. 41. Wet the inside of the tube and wrapping on the piston rod. Pull up the piston.

INFERENCE. Why does water follow it in the tube?

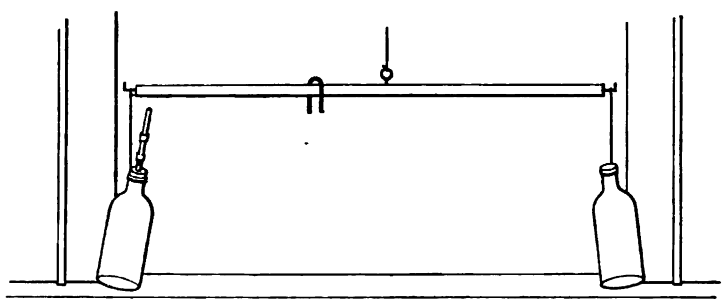
NOTES.

AUXILIARY WORK.

IX.

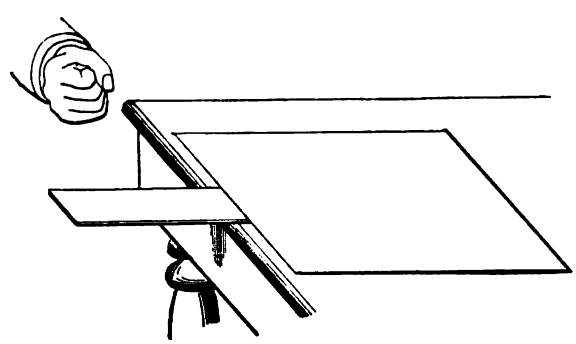
Aux. 10. The rubber bulb of an atomizer, found at drug or rubber stores, makes a valuable addition to your apparatus, increasing the beauty and instructiveness of several experiments in air. Attach it to the rubber tube in Exp. 32, and it represents the pump on the deck of a wrecking vessel, pumping air down to the workmen in a diving-bell.

Aux. 11. Even if you are not provided with an air-pump and delicate scales, it is not necessary to take for granted that air has weight. If you have strong lungs, the following Apparatus will show it clearly; and if you have not, you should practice until you have, for kind Nature has given you a pump good enough for any necessary experiment with air, even that of finding its exact weight, which at the proper time we shall try to do.



Aux. 11.

Suspend in the window a meter rod or yard-stick by a screw-hook or eye, in the center. Drive a tack into each end, on which hang quart or larger bottles, one being tightly fitted with a stopper, glass tube, and rubber tube with plug in end. Then pour shot, sand, or water into the open bottle until it balances the other, with bottoms just above the window-sill. A wire rider easily slid along the stick will enable you to get an exact balance. Suck all the air you can from the plugged bottle, resting several times, and replace plug.



Aux. 12.

Inference. Why does the other bottle now rest upon the window-sill?

Aux. 12. Place a strip of *thin* board about two feet long on the table, with half its length projecting over the edge. Over the portion on the table lay smoothly several thicknesses of newspaper, full page size. Strike the projecting end as hard a blow as you can, and if the blow is not followed by a push, you cannot knock the board off the table.

Inference.

NOTES.

IX.

Exp. 29. Plug every hole in the Apparatus and all but one in the stopper; in this insert the funnel, and fill it with water.

Exp. 30. With the bent tube in the side of the Apparatus, opening under water in a dish, fill the funnel with water.

Exp. 31. Float a cork on the water, invert the Apparatus or a tumbler over it, and press it well down into the water.

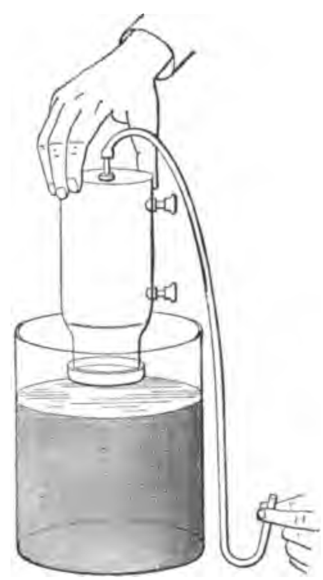
INFERENCES. 1. What fact about air do these three experiments teach you? 2. Compare with the first learned about water.

EXP. 29.

EXP. 30.

Exp. 32. Push the inverted Apparatus down into the water. Blow gently through the tube, and you have a miniature diving-bell.

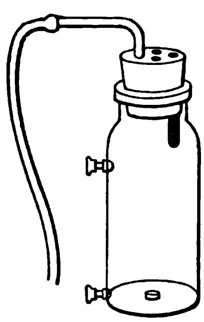
INFERENCE. Why does not the upward pressure of the water force it up into the Apparatus? See Aux. 10.



EXP. 32.

Exp. 33. Plug every hole in the Apparatus (or use a large bottle) and every hole but one, in the stopper; in this insert a short glass tube, and attach to it a short rubber tube with plug in end. Balance the Apparatus or bottle on scales, then remove the plug and suck out all the air you can. Pinch the tube to prevent air entering whenever you stop to rest your throat, and stop sucking when you can exhaust no more air; also be careful not to let water from your mouth enter the tube, as a few drops might spoil the experiment; replace the plug, and return the Apparatus or bottle to its scale-pan. If the scales are delicate enough, and you have performed the experiment well, it will weigh less than before.

INFERENCES. 1. Why? 2. Compare with this the second fact learned about water. For cheap but excellent home-made apparatus for this experiment see Aux. 11.



EXP. 34.

Exp. 34. Insert the stopper tightly in the Apparatus, pour mercury into the hole partly filled by the rattan plug, and suck the air from the Apparatus. (Do not allow mercury to touch a gold ring.)

INFERENCE. What causes the mercury shower? See Aux. 12.

NOTES.

NOTES.

XII.

Exp. 46. Connect two Apparatuses, or an Apparatus and a tin can, by means of a rubber tube. Put a stopper in one and fill the other with water. Fill both, put a stopper in one, and empty the water from the other.

INFERENCE. Why does not the water run in either case?


EXP. 47.

Exp. 47. With the bottom hole open, lower the inverted Apparatus into a dish of water till it is full, then plug the hole and lift it nearly out. While full of water and held with the mouth only under water, uncap the side tube near the bottom.

INFERENCES. Compare with the lever. 1. Where are the arms? 2. What pressure on one arm and not on the other causes the motion? 3. After uncapping the tube, what presses alike on each arm that did not before?

Exp. 48. With mouth and bottom hole open and the Apparatus erect, sink it beneath the surface in a dish of water, and when filled, cover the mouth with a card, held firmly in place. Then lift it nearly out of the water.


EXP. 48.

INFERENCES. 1. Does the water press up against the card? 2. If so, which presses the harder, water underneath or air on top? *Be sure* to write your opinion before trying the next experiment. Be careful, for even older pupils frequently make a mistake in answering this question, when not allowed to find out by experiment.

Exp. 49. Repeat the last experiment, using, instead of the card, sheet rubber, tying it firmly over the mouth of the Apparatus.

INFERENCES. 1. Did you answer the question in Exp. 48 correctly? 2. Explain this one as fully as possible, remembering that the elasticity of the rubber is one force operating to produce the balance. 3. Compare with lever.


EXP. 50.

Exp. 50. Fill the long jet-tube under water, and with finger pressing against the larger end, lift it out of water. Raise the finger a trifle and replace it quickly. Repeat till the water has nearly all dropped from the tube. Try the tube with large opening at each end. Try larger tubes.

INFERENCES. 1. Explain carefully. 2. Explain also why the water does not all run out. 3. If the water did not adhere to the glass, would or would it not all run out?

NOTES.

AUXILIARY WORK.

XII.

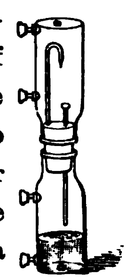
Note. — Make no use of Auxs. 25–30 until they are referred to in the regular work.

Aux. 25. This is a very striking and easily made form of Hero's Fountain, in which a jet of water rises higher than its source. The upper part is the top of a large bottle; the central piece is the longer part of a lamp chimney, like the one used in Aux. 1; the lower part is the Apparatus. The lamp chimney is easily cut at the narrow place by the aid of a triangular file and the gas glass-cutter. All the glass tubes are open at both ends, *c* being a jet-tube passing through the upper stopper, and nearly reaching the lower. Two corks — or, better, rubber stoppers — may be used where one is illustrated, if the same one does not fit both glass pieces tightly enough. For the bottom piece a large, heavy bottle is preferable to the Apparatus. This apparatus may be made with one piece less of glass, by using the long neck and a part of the body of a wine bottle, together with two rubber stoppers, thus dispensing with the lamp chimney; made in this manner, however, it is a short-lived fountain, the reservoir being much too small. Of course, if well made, this apparatus never needs taking apart; for, by inverting it, the reservoir is filled and the surplus of water in the bottle is discharged through the jet-tube. If the tubes do not discharge freely, a little careful shaking of the apparatus will make them do so.

Aux. 25.

Inference. Explain every step both of the working of the fountain and the process of refilling the reservoir.

Aux. 26. This is an intermittent fountain in which the water rises in spurts higher than its source, some of it passing several times from one bottle to the other before the action finally ceases. If the apparatus be carefully constructed, the water strikes the bottom of the upper bottle with considerable force at each throw. The fountain never requires readjusting, and to prepare it for a second period of activity it is necessary only to invert the apparatus until water runs into the lower bottle, as shown in the illustration. It may be constructed of two Apparatuses or, better, of two large bottles, one or two corks or rubber stoppers, and two jet-tubes, the bent one having a smaller opening than the other. The small funnel at the upper end of the straight tube is not a necessity, but it is easier to construct it thus (see Auxiliary Work, sheet V) than to get the tubes accurately enough aligned to work well without.


Aux. 26.

Inferences. 1. Explain the condition of the air in each bottle before action begins. 2. What force produces the first change in atmospheric conditions, and what is the change? 3. What other force comes into play, and what are its results, both visible and invisible? 4. Explain what occurs and why, when the apparatus is inverted.

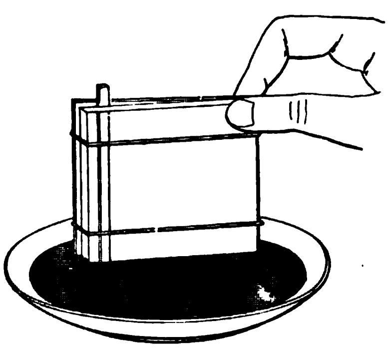
NOTES.

XIII.

Exp. 51. Use all the different sized tubes you have as "droppers." Also, wet them inside and hold them with one end in water and the other open.

Inferences. 1. How does the length of the water column compare with the size of the tube? 2. Is it not the same force that makes a postage stamp stick to the envelope or chalk stick to the blackboard? 3. Are you not using the same force when answering these questions in your books? 4. Give other examples. We call the force which causes particles not alike to stick to each other, *adhesion*, but if the particles which stick together are alike, we call the force *cohesion*. 5. Which force do you overcome when you break a stick or a string? 6. Do both of these forces act in holding water in a glass tube? In tubes, especially when they are small, whether glass or not, we call the force *capillary attraction*, from the Latin word *capillus*, meaning hair. 7. Now, using the word *cohesion*, explain the difference between solids (such as glass, wood, iron, etc.) and liquids, (such as water, oil, etc.). 8. When water becomes a solid, or ice, has it more or less cohesion? 9. What force appears to be the opposite of cohesion? 10. What changes ice to water? See Aux. 18.

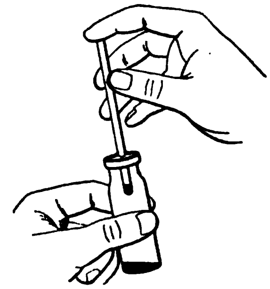
Exp. 52. With a *clean* disc of glass and one of metal (or two of glass), a match, and two rubber bands, construct the apparatus illustrated. Immerse in water to wet the inner surfaces of the plates, then stand in shallow water.



Exp. 52.

Inferences. 1. Illustrate with a drawing, and explain. 2. Look also for a result of the same force in a tumbler of water.

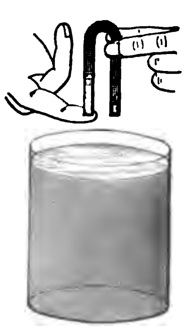
Exp. 53. Place a tube in the mercury in the small bottle. Also use the tube with mercury as a dropper.



Exp. 53.

Inferences. 1. Illustrate with drawings. 2. Compare the two forces in this case with the same in case of water and glass.

Exp. 54. Fill the equal-armed U-tube with water; with the finger cover one end, invert, and holding it perpendicularly, remove the finger.



Exp. 54.

Inferences. 1. Infer why the water does not fall out. 2. Compare with wooden lever. 3. If you consider the surfaces of the water the ends of the lever arms, what presses down alike on each? 4. What presses up alike on each? 5. Which force is the greater? 6. Name all the forces you can that are operating in this experiment. 7. Do they all assist in holding water in the tube or not? Repeat the experiment, using U-tube with unequal arms. 8. Infer, and compare with lever, explaining as fully as possible. Repeat again with first U-tube, inclining it till the water runs out. 9. Where is the fulcrum of these water levers always located? 10. Draw diagrams of levers representing each of the above conditions.

NOTES.

AUXILIARY WORK.

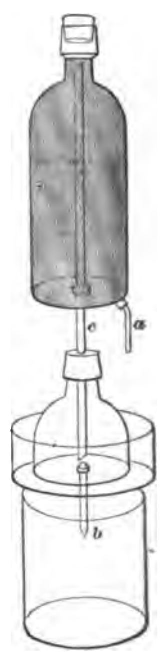
XIII.

Aux. 18. Place a large sponge in a plate half filled with water. Note what takes place. With a few drops of ink or bluing, color a little water in a shallow dish and stand a lump of sugar in it. Note the effect. Stand a piece of cane, rattan, or blackboard crayon, in a little turpentine or kerosene oil, and after an hour or two, according to the length of the piece used, hold a lighted match to the upper end.

INFERENCE. Explain the use of blotting-paper, candle- and lamp-wicks; and mention any other similar cases you can think of.

NOTE. — Auxs. 27 and 28 should not be used until referred to in the regular work.

Aux. 27. This is an intermittent fountain made of an ordinarily shaped quart bottle, the top of another used simply as a stand for the first, the bottom of a larger bottle, a glass fruit jar, and pieces of tubing and corks. For greater stability, the apparatus-tube *c*, which is bevelled at both ends, should touch the dish at its lower, and the cork at its upper end. It needs not be so long as shown in the cut; it would better be short enough to allow the bottle to rest upon its stand, into which it is firmly fitted with a cork. Tube *a* is the one that furnishes the intermittent stream, and if the apparatus be adjusted with care, another tube like it may be fitted to the opposite side of the bottle. Without *very* careful adjustment, however, air will enter one tube, and thus prevent an intermittent flow from either; hence you would better make the fountain with a single tube at first, then add the second if desired. A cap is placed upon this tube while the bottle is being filled and corked. Tube *b* leading from the large dish to the jar below furnishes a steady stream, and has a smaller opening than *a*; if small enough, the fountain will run for an hour or more, intermitting perhaps every other minute. If the holes in the bottles used must be drilled, have the one in this dish at or near the center, but if you make them with files, the easiest way is to make the hole in this dish at the edge like the one for tube *a*, and make *b* with a double bend leading into the jar through a notch filed in the edge of its mouth. If large, the stand may also need notching.



AUX. 27.

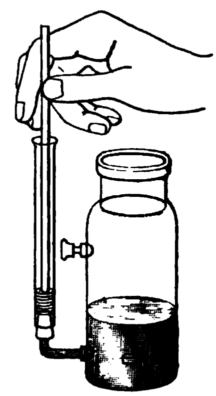
Aux. 28. This might be called a fountain sponge. The principle of its action is the same as that of the common fountain ink-well. The lower halves of two bottles are connected by a short piece of tubing. In one of the bottle-bottoms is placed the sponge; the other is placed like a cap over the mouth of a bottle filled with water, which is then inverted. The sponge keeps moist for weeks or months, according to size of bottle and condition of the atmosphere. The water escapes only by evaporation from the sponge, if the latter is not removed from its dish. It may be used as a pen wiper, or for moistening the gummed surfaces of stamps and envelopes.


AUX. 28.

VIII.

Exp. 26. Arrange the Apparatus the same as in Exp. 25, but insert a short jet-tube in one hole of the stopper, or in a side hole. With a jet-tube in the stopper, hold the palm of one hand about two feet above; seize the piston rod at a point where the plunger end, when pushed in, will not quite reach the bottom of the Apparatus; then push it down suddenly.

Exp. 27. Withdraw the piston to the top of the tube, measure the length of the tube thus filled with water, and also the depth of the water in the Apparatus. Push the piston to the bottom of the tube, and find how much the water from the tube increases the depth of water in the Apparatus. If the piston is not air-tight, fill the tube and the Apparatus with water, cork the tube, then pour nearly all the water from the Apparatus, and measure. Uncork and measure again.



EXP. 27.

INFERENCES. 1. The Apparatus is how many times the size of the tube? 2. With one pound pressure on the surface of water in the tube, how many would be required on the water surface in the Apparatus to balance? See Aux. 8, sheet VII.

Exp. 28. Fill both the Apparatus and the tube with water, as in Exp. 20, and tie sheet rubber over the mouth. Place weights of four or five pounds on the Apparatus, and blow into the tube.

INFERENCES. 1. Why can you lift so much with so little force? 2. How would you determine the number of pounds lifted by an ounce of force applied through the tube? 3. Compare with lever.

NOTE. — By blowing through the tube you can apply only about an ounce of pressure. See Aux. 9, sheet VII.

While performing the experiments on these seven sheets, you have learned something about the so-called physical properties of water. You can also mention one force that has a great deal to do with these properties. There are other forces always operating which you will discover in connection with the study of the next subject — Air. Before beginning the study of air it would be advisable that you state again, clearly and briefly as possible, all you have discovered about water.

NOTES.

NOTES.

VII.

Exp. 21. Lower and raise the stopper alternately, and see if you can tell with your eyes shut when it enters or leaves the water. Try also the wooden ball.

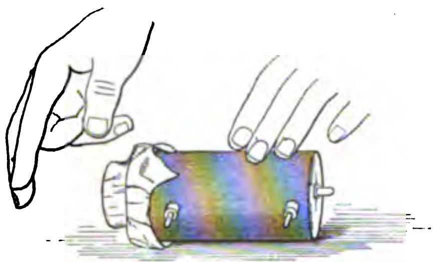
Exp. 21.

INFERENCE. Explain as fully and carefully as you can why the stopper when under water seems to weigh less, and why the ball floats.

NOTE.— Later in our course we shall have several very interesting experiments similar to this one; but you ought to see clearly *now* what causes this *buoyant* force of water, as it is called. Is a fish or a stone as heavy in water as it is out? Explain.

Exp. 22. Push the Apparatus along the table with your pencil.

INFERENCE. In what one direction only is the pressure which your hand applies to the pencil transmitted to the Apparatus?



Exp. 23.

Exp. 23. With the Apparatus full of water, remove the jet-caps, and tap gently on the rubber with your fingers.

INFERENCE. Compare with Exp. 22, and explain the difference between solids and liquids in *transmitting* applied pressure.

Exp. 24. With the Apparatus full of water, step to an open window and blow through the rubber tube. Determine by experiment whether you have to blow any harder to raise several jets of water to a given height than to raise one. See Aux. 7.

Exp. 24.

Exp. 25.

Exp. 25. Fill the Apparatus with water, insert the stopper tightly with one hole open, and measure the part of the stopper above the glass. Carefully push the piston rod or "plunger" through the open hole to the bottom, and again measure. The measurements should be made with care.

NOTES.

AUXILIARY WORK.

VII.

Aux. 7. A fine auxiliary piece may be made by tying sheet rubber over the large end of a lamp chimney. Fill the latter with water, and insert the stopper or a cork with tubes, as illustrated, and press on the rubber.

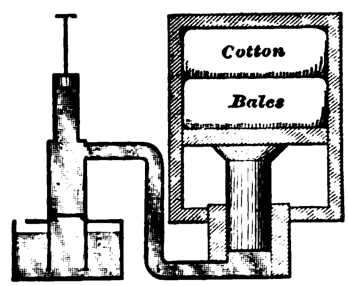
AUX. 7.

AUX. 8.

Aux. 8. (Study this figure, if not provided with the apparatus.) Connect a tube with piston to two others of the same size, as illustrated. With the water at equal depth in each, insert the piston in the middle one, and transfer the water to the other two.

INFERENCE. How much pressure on the surface of the water in each will balance one unit on the surface of water in middle tube? Does the amount of pressure transferred to each side tube bear the same relation to that on the piston, as the amount of water transferred bears to that at first in the middle tube? What things are in the same relation to each other as applied and transmitted pressure? Did you make them so in inferences to Exp. 27?

Aux. 9. This picture illustrates the "hydrostatic" or water press, a machine which enables one with but little force to exert great pressure. A pump stands in an open tank of water. In the pump, a little above the level of the water in the tank, is a closed door-shaped valve, which opens upward when the piston is pulled up, allowing water to enter and fill the pump. Why it does so, you probably cannot see at present, but you will when you study the next subject — Air. In the pipe connecting the pump and the press is a valve opening towards the latter. When the piston of the pump is pushed down, of course the pump-valve closes, and as the water cannot be pushed out the way it came in, it goes through the other door to the press.



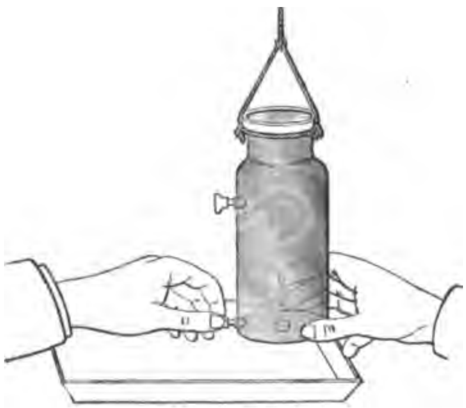
AUX. 9.

INFERENCES. 1. Upon what fact about liquids does the great power of this press depend? 2. Compare it with the lever, and point out all the resemblances you can. 3. If the force exerted by the press is one hundred times as great as that applied to the pump, what two measurements are to each other as 100 to 1? 4. If you consider this a "water lever," which of the measurements must be considered as the long arm, which the short?

NOTES.

VI.

Exp. 18. If provided with auxiliary apparatus No. 5 (see page 4), perform Exps. 18 and 19 with it. The Apparatus is not tall enough to make Exp. 18 very striking, but for 19 it does very well. Suspend the Apparatus full of water just above a window-sill,



Exp. 18.

Exp. 19.

by as long a string as possible. Make a mark under the edge of it, or place the edge of a pan under that of Apparatus. Steadying it with one hand, carefully remove the jet-tube from the lower side hole, and let it go at the same time.

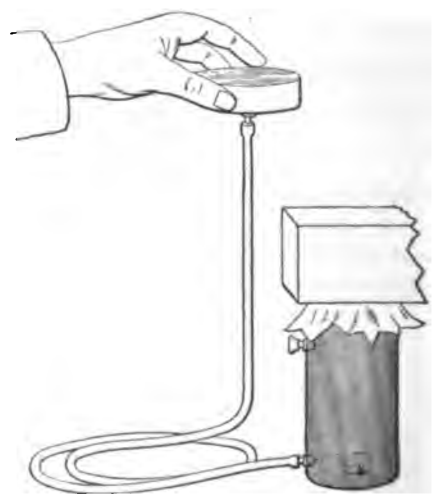
Inference. Why does the Apparatus swing away from the jet of water?

Exp. 19. With the Apparatus still hanging in the window, place the elbow tube in the lower side hole and fill with water.

Inference. At exactly what point is the pressure that causes it to rotate applied?

Exp. 20. Fill the Apparatus and rubber tube with water. To fill the latter, let it lie on the table, and pour water into the Apparatus; then, when the water begins to run out of the tube, plug the end with capped jet-tube. When the Apparatus is as full as possible, tie the piece of sheet rubber over the mouth, and place a weight of a pound or more upon it. Insert a funnel in place of the plug. Pour water into the funnel (see note to Aux. 6), and raise it to the length of the tube.

Inference. Explain why so little water raises so heavy a weight. See Aux. 6.



Exp. 20.

NOTES.

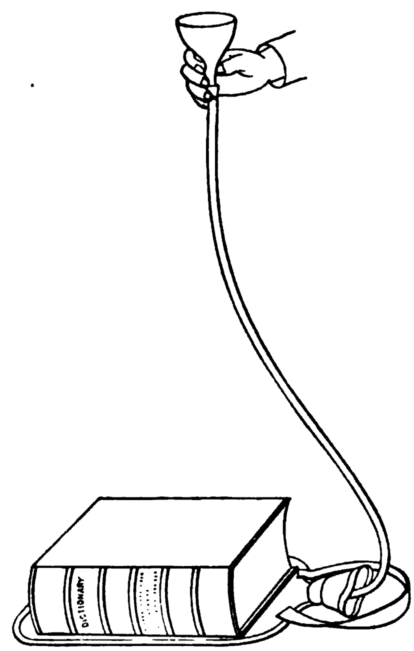
AUXILIARY WORK.

VI.

Aux. 5. (See cut on sheet V.) Exps. 18 and 19 are much better performed with a tall bottle. A quart ink or wine bottle does very well; a hole is much more easily made with a file in the edge than in the side of a bottle, and does just as well for these experiments. Still better and cheaper is a tin tube a foot or more long, corked at the bottom, and provided with a wire bail. Make the holes just above the cork, and insert tubes from the pupils' sets. If the class is large, it is better to have a piece for each experiment and but one piece in a window to which pupils go in turn to inspect it. Exp. 19 may be done in a variety of ways, thus: with both tubes horizontal in a large tin pan to catch the water; with the pan nearly full of water, the tubes submerged; with one tube horizontal, the other at any angle; with both tubes at different angles, imitating a lawn fountain.

No other auxiliary apparatus is worth so much in proportion to its cost as this; while performing Exp. 19, Aux. apparatus 4 may be combined with Aux. apparatus 5 by holding its jet-tube so that it will play into the top of it, thus prolonging the experiment.

Aux. 6. Procure a three or four quart hot-water bag.* Attach to it several feet of rubber tubing by means of a perforated cork and a short piece of glass tube. Place the bag upon the floor with a piece of board over it, on which stand or place heavy weights; then pour water into the funnel at the end of the tube.



Aux. 6.

NOTE.— To make a funnel; if gas is available with which to cut glass (see sheet 4), use the top of a bottle. With a rat-tail file make a hole in a cork that fits tightly, and insert one of the short glass tubes. Or take the pressed tin cover of the baking powder can used in Exp. 16, and make a hole in the center (see Aux. 1), pushing the tin outward, and fit glass tube to it with a short piece of rubber tube.

---

*A two-quart bag costs from eighty cents to one dollar, according to the quality. A three-quart bag, which is a much better size for the experiment, costs about twenty-five cents more.

NOTES.

III.

See Auxiliary 1, page 4. If not provided with the apparatus, study the picture.

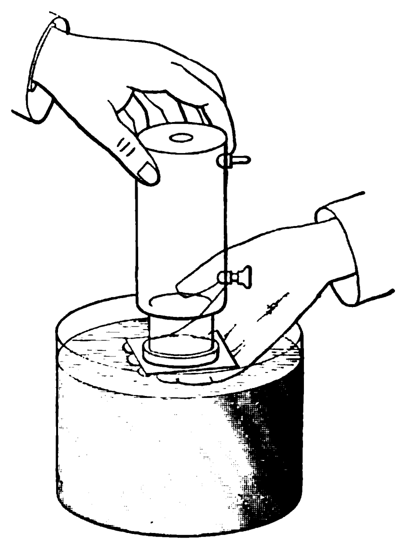
Exp. 8. Insert a short jet-tube into the bottom hole of the Apparatus, with small opening inside, and press it well down into a jar or pail of water.

Exp. 8.

INFERENCE. In which direction does the water press?

Exp. 9. With bottom hole open, place a card over the mouth of the Apparatus, invert, and press it down into jar of water. Repeat, using a disc of metal (iron, zinc, or lead) and also one of glass. The metal and glass discs must be held firmly against the Apparatus till immersed two or three inches. If your jar is not large enough to admit the hand, keep the disc in place by means of a string or wire passed under it, the ends being held in the hand. As the water leaks in until the disc finally falls, compare its height inside and outside of the Apparatus.

INFERENCES. 1. Why does a heavy disc fall sooner than a light one? 2. Compare with the lever. 3. What force on one arm is always the same if the Apparatus is pushed to the same depth? 4. What two forces on the other arm are not the same? 5. When are the two less, and when are they greater, than the one force?



Exp. 9.

Exp. 10. Can you illustrate with marbles or by a drawing, how the force of gravity causes water to press upward as well as downward and sideways?

Exp. 11. Insert the three tubes in the stopper as illustrated, with the lower openings all at the same level. Immerse the lower ends of the tubes in water and notice in which direction the water must press in order to enter each; observe height to which water rises in each. Be sure that the upper ends of the tubes are not stopped with water.

Exp. 11.

INFERENCE. Compare pressure in all directions at the same depth.

LESSON IN REASONING.

Compare Exp. 11 with Exp. 7 and Aux. 1. 1. Tell what you can without more experiments about downward pressure at different depths. 2. How does upward pressure two inches below the surface compare with that one inch below?

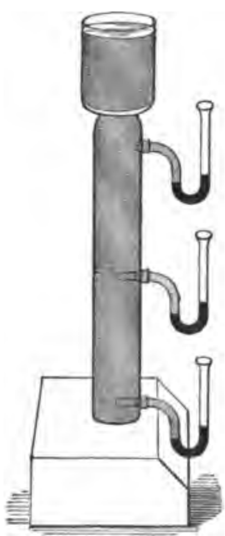
NOTES.

AUXILIARY APPARATUS AND EXPERIMENTS.

III.

It is very desirable that you make the auxiliary pieces of apparatus, or at least some of them, and perform the experiments. But if you do not, a careful study of them when ever they are referred to in your regular lessons, will doubtless be more or less helpful.

Auxiliary 1. This apparatus is more easily made with a tin tube than with a lamp chimney. Obtain a tube of any size or length; a piece of speaking tube about 15 inches long will answer. Cork the lower end, and stick it in a hole bored in a block of wood. The latter serves as a stand. With an awl or a sharp nail, punch three holes equally distant from each other, as in the illustration. Enlarge them with rat-tail file, twisting it and pushing the edge of the tin inwards, so as to make a lip or "burr." Make the holes equal in size to those in the "100 in 1 Apparatus."



AUX. 1.

If desired, repeat Exp. 7, using jet-tubes from pupils' set. For showing steady side pressure and its *exact law*, insert the U-tubes with bends each half full of mercury; then fill tube with water, and observe not only the general effect upon the mercury, but measure the amount raised in each tube and compare with corresponding depths of water.

Infer *exact* law of side pressure. 1. Can you see a lever and its weights inside each tube? 2. What constitutes the lever and what the weight upon each arm? 3. At what point in each tube is the fulcrum?

NOTE.— To avoid confining air in the tubes, pour in water until it runs into first tube, then carefully pour a little mercury into tube funnel. Treat the second tube the same way, then pour more mercury into first if necessary, etc. To make this experiment of some aid to those not provided with the apparatus we have violated our general rule, which is to show the apparatus in condition for the experiment, and not during it. In this case we have shown it in progress, as the pupil should, whenever he makes a drawing to illustrate an experiment.

CAUTION.—When handling mercury, be careful not to allow it to come in contact with a gold ring, for the two metals will amalgamate, giving the ring the appearance of silver. Should such an accident happen, heating the ring *cautiously* will drive off the mercury, but the gold will need reburnishing.

A LETTER FROM THE AUTHOR TO THE PUPIL.

MY DEAR YOUNG FRIEND:

I want to talk with you a little before we begin work — or play — I may as well call it, for tops, balls, and marbles are by no means the most interesting things we use in this fascinating scientific game. That it is as enjoyable as play to children of twelve to fourteen years I *know*, because the pupils in my Boston school, of their own accord, frequently use their recess hour for it, and often come before school and on Saturdays in order to do more experimenting than their regular hours permit. That it is the very best way to learn about the world we live in, all the best teachers believe, because each pupil is learning directly from a better teacher than any living, — NATURE. Do you remember how Longfellow says that the great and good Professor Agassiz learned his lessons?

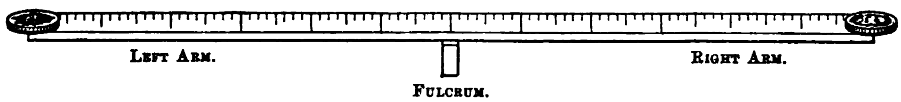
> "And Nature, the old nurse, took
> The child upon her knee,
> Saying, 'Here is a story-book
> Thy Father has written for thee.'
>
> "And he wandered away and away,
> With Nature, the dear old nurse,
> Who sang to him night and day
> The rhymes of the universe.
>
> "And whenever the way seemed long,
> Or his heart began to fail,
> She would sing a more wonderful song,
> Or tell a more marvellous tale."

Now I am going to ask you to adopt a motto that I write upon my blackboard the first day of every school year, viz.: "NATURE is our teacher; all the knowledge we possess has come through the patient study of her laws." Then, whenever you are tempted to ask your *school* teacher anything about Physical Science, I would ask you to stop and think, "Why, NATURE is my teacher; I must ask her." "But," say you, "I don't know how." That is true, and that is the reason I have arranged this series of questions (experiments) for you in order to tell you how to ask them. If you do as I direct, you will not only be greatly interested and instructed by the answers you obtain, but what is *far* better, you will learn how to put questions yourself. Then you will continue through life studying Nature wherever you are. You will become an original investigator, and possibly a discoverer and an inventor. All the great discoveries and inventions were made by men who first learned how to put their questions to this GREAT TEACHER and interpret the answers.

ELEMENTARY PHYSICAL SCIENCE.

I.

THE LEVER.



APPARATUS. A foot rule or similar stick; a dozen button dress-weights, nickels, cents, iron-washers, or anything convenient for weights; a small piece of wood for a fulcrum. To economize time, the upper surface of the fulcrum should not be less than $\frac{1}{4}$ inch wide, especially for young experimenters. There is on the market a small rubber eraser of excellent size and shape for a fulcrum. It is a little more than an inch long, with each side $\frac{1}{4}$ inch wide. "Button dress-weights," though a trifle more expensive than iron-washers, are more uniform in weight, and being of lead, may be easily trimmed. *Exact* uniformity, though desirable, is not essential.

DIRECTIONS. The best way to experiment with your lever is to balance it on the fulcrum, with its central mark over the center of the block. Hold it with your left hand near the end of its left arm, while placing, — first, the weights as indicated in diagram, then the balancing weights. If you make no mistake, and place the centers of the weights as nearly as you can over the correct lines, the lever will balance after your hand is removed.

Diagram 1 (on page opposite) represents the lever, as illustrated above, with one weight on each arm 6 inches from the fulcrum. Find by experiment how many weights on right arm 3 inches from fulcrum will balance one at the end of left arm, and put the number in the proper place on diagram 2.

Continue in the same way till you learn how to determine without experiment, then write the answers and test by experiments afterwards. If, after doing the first six or seven experiments, you cannot determine, make up some of your own till you can; then finish the ones given. If you have studied algebra, express each experiment in form of an equation with the sign = in place of the fulcrum. Express in writing what you have discovered to be the principle of the lever.

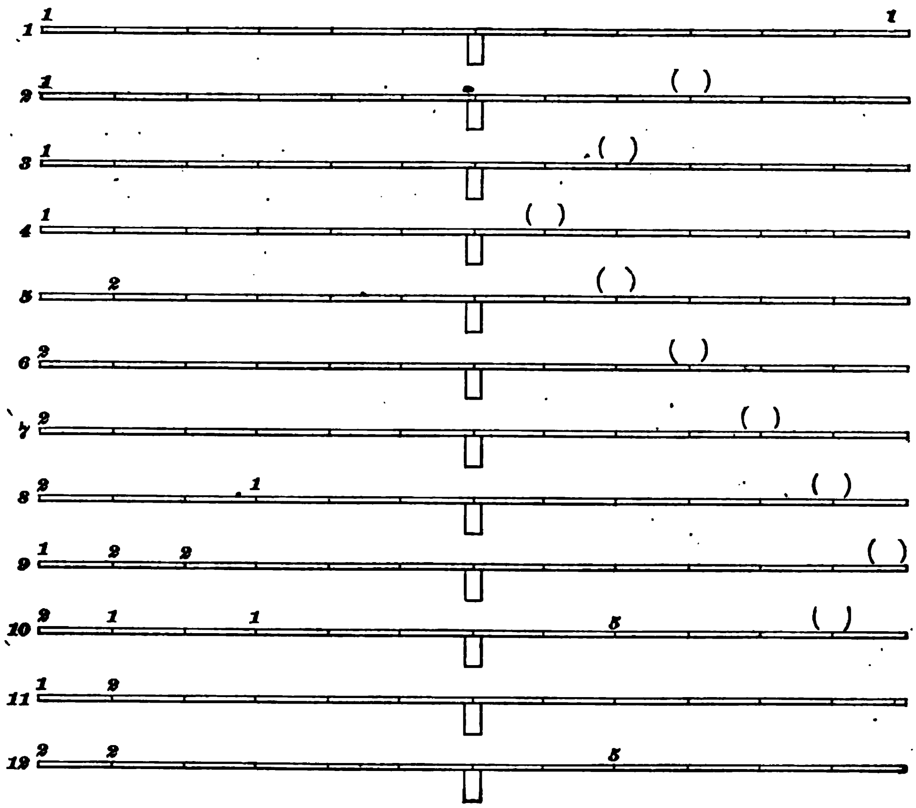
Where should you place 4 weights on diagram 11? Where 3 more on diagram 12?

PROBLEM 1. Two boys are playing sea-saw on a plank balanced across a log. One is twice as heavy as the other. Which should sit nearer the log, and how much? Illustrate with picture or diagram.

PROBLEM 2. A man uses a crowbar 6 feet long, and places a stone for a fulcrum 6 inches from the lower end. With 100 pounds' pressure at the upper end, how much can he lift at the lower? Illustrate.

Make up a few lever problems of your own and illustrate them. Mention as many objects as you can think of that illustrate the principle of the lever.

NOTES.



PROB. 1.

PROB. 2.

ORIGINAL PROBS.

Now let me tell you how to study this course, that it may afford you the most pleasure and profit. *First.* Perform every experiment in order. Do not omit one because it looks so simple that you think you know all about it. None of us knows *all* about anything. *Second.* Always experiment carefully and thoughtfully. If you work hurriedly, carelessly, or without watching to see everything that happens, and without thinking out for yourself the reason for it, it will do you little or no good. And of course, if you must not be told *why* anything happens, you should not tell your classmate and so deprive him of the pleasure and benefit of discovering for himself. Possibly you may perform an experiment and not see the *why* of it at first; if so, give it a little careful thought, remember the *what*, and perhaps the very next experiment will show you the *why*. If, however, two or three experiments do not help you out of your difficulty, probably you have not done the previous work well enough, and would better review it. *Third.* When you see what an experiment teaches, you must tell it in your own language on paper. It will not do you half the good to give it in spoken words; you must *write* it. For this purpose we provide you with blank leaves. Number each inference — that is, what the experiment teaches you — and write it directly opposite, at the time you do the experiment. Your thought being chiefly on the experiment and what it teaches, you will not express it in the very best language, now, without mistakes; therefore you should rewrite it. Let me tell you our method, for it is the best we have yet discovered. After experimental work our pupils have an hour for writing the lesson; this they do on ruled note-books in the form of a chapter on science. Each lesson is dated; it begins at the top of a page and is written only on the right or else the left hand side (always the same), the other being left for corrections. The experiment, observation, and inference are given; the first is usually illustrated with a small drawing.[1]

The pupils preserve their books and at the end of the year it is a good plan to have them bound. Pupils prize these books more highly than any others in their libraries, for they are entirely of their own making. What I ask you to do is one thing that did much towards the discipline of George Washington, for we are told upon good authority that "he made his own school-books."

Hoping that you will do likewise and meet with success through life, I am your true friend and fellow-student,

F. H. BAILEY.

6 Marlboro Street, Boston, Mass.

[1] Suggestions for Correcting Books. After school I look over the work, and with red pencil mark the mistakes with such signs as *gr.* for grammatical error; *sp.* under word for mis-spelled; a wrong or unsuitable word or expression is marked underneath *u.w.* or *u.ex.;* a statement that is wrong, or that would better be reconsidered and rewritten, is inclosed in parenthesis and marked with an interrogation point thus (—)? The next day the pupils correct their mistakes, changing nothing on the written page but making their corrections directly opposite. Then the next time the books are inspected, if all corrections are satisfactorily made, an *A* (accepted) is placed at the top of the page.

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